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PRE-ENGINEERING ASSESSMENT

OF

AN ENERSOLVE DEMONSTRATION PROJECT

AT

IPSCO INC.

REGINA, SASKATCHEWAN

FOR

DEPARTMENT OF ENERGY, MINES AND RESOURCES

CANMET, ENERGY RESEARCH LABORATORIES

OTTAWA, ONTARIO

CONTRACT SERIAL NO. OSQ84-00410
DSS FILE NO. 02SQ.23440-4-9283-5
KEEN NO. 7135-01
APRIL 1985

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1.0 Executive Summaries

1.1 Executive Summary

The energy utilized in reheating ingots in soaking pits prior to hot rolling into slabs or coiled sheet is significantly influenced by both pit design and external factors.

Of the external factors, the time between pouring the ingot and placing it in the soaking pit is perhaps the most significant. Delays in delivery of the ingots result in a cooling of the steel and hence additional energy is required to reheat the material to working temperature.

Among the pit design features, recuperation and combustion control offer substantial potential for conserving energy. Our examination of the recuperator performance at the IPSCO INC. plant in Regina indicates that operating savings of 12% are readily available through the installation of recuperators. Over the nine non-recuperative pits at the Regina plant annual fuel savings of the order of 2.85×10^6 cubic meters of natural gas, at a cost of $353,550.00, are available. The estimated capital cost of the recuperator retrofit is $1,890,000.00, resulting in a simple payback of approximately five years. Combustion system improvements through the provision of oxygen trim combustion controls, it is extimated, could provide fuel savings of the order of 4% or 1.32×10^6 cubic meters of natural gas per year at a cost of $163,680.00. The estimated capital cost of the retrofit on all thirteen pits is $325,000.00, resulting in a simple payback of approximately two years.

The energy saving techniques discussed in this report are widely applicable to other steel plants and process industries. A brief survey of the use of recuperators in the Canadian

steel industry indicates that there exists possible savings of more than $2 million per year through the use of recuperators. Combustion control improvements could contribute another $1 million.

1.2 Sommaire Administratif

L'énergie utilisée pour rechauffer les lingots dans des bassins de trempage avant de les laminer à chaud pour en faire des plaques ou des rouleaux est influencée de façon significative, et par la conception du bassin, et par des facteurs externes.

Des facteurs externes, le temps entre le moment où le métal est coulé et celui où il est placé dans le bassin de trempage est peut-être le plus important. Des délais dans la livraison des lingots se traduit par un refroidissement de l'acier et il faut donc davantage d'énergie pour ramener le matériau à une température où on peut le travailler.

Parmi les caractéristiques du bassin, la récupération et le contrôle de la combustion offrant des possibilités substantielles de conservation d'énergie. Notre étude du rendement du récupérateur de l'usine IPSCO INC. de Régina indique que des économies d'exploitation de 12% sont facilement réalisables grâce à l'installation de récupérateurs. Comparé aux neuf bassins de l'usine de Régina, des économies annuelles de combustible de l'ordre de 2.85×10^6 mètres cubes de gaz naturel à un coût de $353,550.00, sont possibles. Le côut en capital de l'installation du récupérateur est estimé à $1,890,000.00, et devrait être récupéré dans cinq ans environ. Nous pensons qu'en améliorant le système de combustion par l'équilibrage de l'oxygène on pourrait faire des économies de combustible d'environ 4%, soit 1.32×10^6 mètres cubes de gaz naturel par an, d'un montant de $163,680.00. Le côut en capital de l'aménagement des 13 bassins est estimé à $325,000.00, et il devrait être récupéré en deux ans environ.

Les techniques de conservation de l'énergie étudiées dans ce rapport sont largement applicables à d'autres aciéries

et industries de transformation. Une brève étude sur l'emploi de récupérateurs dans l'industrie métallurgique canadienne indique qu'il existe des possibilités d'économies de plus de $2 millions par an si on utilise des récupérateurs. Les améliorations du contrôle de la combustion pourrait faire économiser $1 million de plus.

2.0 Introduction

Keen Engineering Co. Ltd. were commissioned on March 1, 1985, by Supply and Services Canada to perform a pre-engineering assessment of an Enersolve demonstration project. Our response to the original request for proposals is enclosed as Appendix A.

The project is an examination of the soaking pit process in steel manufacturing at the IPSCO INC. plant in Regina, Saskatchewan. The preamble to the statement of work included in the request for proposal (RFP) illustrates the thrust of this study very well and is accordingly reproduced below.

"Preamble

The Enersolve Program under which proposals are now being requested is concerned with increasing the efficiency of utilization of oil and gas in industrial boilers, kilns and furnaces. It is assumed at the outset that such process heating equipment, particularly if ten or more years old, may not be operating or operatable at maximum attainable efficiency of fuel use, and that some scope may exist for technically upgrading the installation to achieve greater fuel economy. The manner for obtaining more efficient fuel use may vary from the simplistic case of better control instrumentation to microprocessor control of fuel to air ratios and flow rates to follow load. It is axiomatic that the cost of equipment retrofit should be recoverable through fuel savings over a period of time acceptable to the equipment owner.

Previous studies have been carried out for the Enersolve Program on industries such as pulp and paper, cement and

brick manufacturing, food, mining, chemical, sewage treatment and insulation manufacturing. These looked at the performance of boilers and process heaters. It is anticipated that the present RFP will solicit proposals relevant to other industrial sectors, again primarily concerned with the performance of oil and gas fired equipment.

Bidders are invited to submit proposals for studies on one, or a maximum of two, specific sites in any of the following industries:

- o Billet reheating in steel manufacturing
- o Brewing and distilling
- o Oil refining
- o Secondary or tertiary oil recovery
- o Primary metal extraction or refining
- o Foundries
- o Dairy industry
- o Brick kiln"

The IPSCO INC. steel making process utilizes ingots, as opposed to billets, which are reheated in gas fired soaking pits prior to being hot rolled into coiled sheet steel. Ingots are similar to, but larger than, billets, weighing 15 to 25 tons, and measuring 110 inches high by 23 to 34 inches deep by 42 inches to 73 inches wide each. The term 'soaking pit' is derived from the fact that the ingot is soaked in hot combustion products.

A proposal was submitted to investigate the soaking pit, as opposed to billet reheating, process and accepted.

The units used in this report are primarily imperial as the majority of the information obtained was in imperial units and

this appears to be the working system of the steel industry at the present. The one plant exception is temperature readings which were taken in degrees Celsius but are converted to degrees Fahrenheit for consistency. Also, natural gas savings are reported in cubic meters as this is the unit of measure employed by the utility company.

Section 1, Executive Summaries, provides a concise summary of our findings in both English and French.

Section 2, Introduction, provides an introduction to the topic under study and an outline of the report format.

Section 3, Scope of Work, outlines the refined scope of work contained in Keen Engineering Co. Ltd.'s proposal and which forms the basis of this report.

Section 4, Steel Making at IPSCO, presents a brief description of the complete process in an effort to better explain the role of soaking pits in the production of steel.

Section 5, Heating Steel for Hot Rolling, presents further background information on just why and how steel must be reheated prior to forming or rolling.

Section 6, The Soaking Pit Process, describes the nature of the reheating process which takes place in soaking pits.

Section 7, Pit and Equipment Description, presents specific details of the soaking pits at the IPSCO INC. Regina plant.

Section 8, Test Data, presents the test data accumulated in conducting this study.

Section 9, Data Analysis, explains the computations performed on the data and interprets the results of these computations.

Section 10, Related Discussion, presents further generic discussion of other energy saving possibilities in soaking pits.

Section 11, Conceptual Design, presents a brief overview of how the energy savings described previously might be realized. Retrofit cost estimates are also presented.

Section 12, Economic Analysis, compares energy savings and capital costs in order to determine payback periods for the retrofit project.

Section 13, Other Potential Applications, presents a brief discussion of the application of the previously discussed retrofit measures to other steel manufacturing facilities and fuel fired appliances in general.

Section 14, Conclusions and Recommendations, presents the conclusions we have reached through this study and makes related recommendations.

Section 15, Further Project Costs, presents estimates for the further phases of this study.

3.0 Scope of Work

The scope of work for this specific project was refined from that contained in the RFP to that contained in Keen Engineering Ltd.'s proposal. That refined scope of work is reproduced below.

"Our proposed scope of work has seven main elements.

(i) Through extensive on-site investigation and testing establish data base including fuel use, equipment and combustion efficiencies and load characteristics;

(ii) Through above field work assess effectiveness of existing equipment;

(iii) Assess potential for:

(a) heat recovery on nine soaking pits currently without economisers;

(b) combustion control improvements;

(iv) Perform conceptual design work based on results of elements (i) to (iii), inclusive;

(v) Estimate the economic benefit of the proposed upgrading, including capital and maintenance costs;

(vi) Briefly extrapolate results and estimate potential for application to other similar facilities;

(vii) Estimate project costs for remaining three phases."

4.0 Steel Making at IPSCO

The IPSCO INC. Regina steelworks is 100% steel scrap sourced and has an annual capacity of one million metric tonnes of crude steel. In preparation for melting, up to ten types of scrap are loaded into the charge bucket in proportions determined by the metallurgical department. The scrap is loaded into the furnace by overhead crane, using three or four charges per heat.

IPSCO INC. employs two split shell water cooled electric arc furnaces rated at 125 and 132 tonnes nominal capacity per heat. Electric arc furnaces are shallow steel cylinders lined with refractory brick.

The roof of an electric furnace is pierced so that three carbon or graphite electrodes can be lowered into the furnace, and these electrodes give the electric arc furnace its name becuase, in operation, the current arcs from one electrode to the metallic charge and then from the charge to the next electrode. This provides intense heat.

Once the sorted scrap has been placed into the hearth of the furnace, other elements may be charged in the furnace prior to melting down. If the metallic charge is too low in carbon, additions of coke or of scrap electrodes are included with the scrap.

The top o the furnace is swung into position and the electrodes are lowered through the roof. The electric power is turned on creating a loud roar. The heat resulting from the arcing between electrodes and metal begins to melt the solid scrap. Through a chemical interaction, impurities in the steel rise into the molten slag which floats on top of the melt. The furnace is tilted slightly and much of the slag containing impurities is raked off through the charge door.

The furnace is tilted forward so that molten metal may pour out the taphole through the spout. The slag comes after the steel and serves as an insulating blanket during tapping into a ladle.

The temperature is measured and a sample is taken and chemically analysed to ASTM, CSA, customer, and internal specifications. The bath is then stirred to a specified temperature while the operator awaits the chemistry results. When the chemistry results are available, precise final alloy trim additions are made if necessary.

The method of handling raw steel from the furnace is to "teem" it from the ladle into ingot molds of various sizes and shapes. To do this, the ladle containing steel recently tapped from the furnace is lifted by hooks suspended from an overhead crane and is carried to a position above the cast iron ingot molds.

IPSCO uses two methods of teeming steel into ingot molds, top and bottom pouring.

When top pouring, the ladle is positioned over the mold which has been purged with an inert gas and capped with aluminum foil. Prior to opening the slide gate, an argon distribution "doughnut" is fixed to the bottom of the ladle, which produces a boundary layer of inert gas around the liquid stream, minimizing oxygen interaction during teeming. When the teeming begins, the aluminum foil cap is ruptured by the liquid stream, and the mold fills at a rate designed to produce the best combination of surface and internal quality.

IPSCO bottom pours a selected proportion of its steel production. Six molds are positioned on evenly spaced spokes with a central trumpet in the hub, through which the steel

is funneled. The steel is teemed from the ladle through an argon shroud to prevent reoxidation, and all six molds fill simultaneously. The relatively slow rate of rise and the lack of turbulence during mold filling is designed to give superior surface condition.

After the ingots have cooled sufficiently, they are stripped from the molds and transferred to the soaking pits where they are heated in preparation for rolling. More will be said of the soaking pit process in later sections.

The first station on the rolling mill is the 2 HI slabbing mill which rolls the ingots into slabs of final specified width. After slabbing, the lead and tail ends are cropped and visually inspected before proceeding to the 4 HI intermediate reversing roughing mill, where the controlled rolling procedure begins. Water is used to control temperature and remove scale from the steel surface. The strip proceeds to the 4 HI reversing finishing mill where it is reduced to its final specified thickness.

At the upcoiler, the strip is checked for chemistry, dimensional accuracy, and general condition before being weighed and identified.

When it exits the Regina rolling mill, the coiled produce is ready for finishing or transportation to customers or other IPSCO INC. facilities for further processing.

5.0 Heating Steel for Hot Rolling

5.1 General

The steel, while in the form of an ingot, can serve no useful purpose. It must be reduced in cross sectional area and formed into some useful shape. This is accomplished in several stages by what is termed hot forming the metal, by rolling into strip or sheet.

Ingot structures in general are coarse, fragile, and will rupture easily when subjected to rolling operations. The higher the temperature of the metal prior to hot working, the more readily it can be rolled. For this reason the ingots are heated to temperatures of 2050 to 2450^{o}F in soaking pits before rolling.

This heating must be conducted in an atmosphere which will prevent excessive oxidation or scaling of the surface of the material.

The temperature at which rolling will take place should be adequate to allow the deformation of the material without the need for excessive power and to ensure that after the required hot working the material is at the temperature for further processing. Extreme care is taken in the heating of steel, both in the ingot form and slab, bloom and billet reheating. The results of high heating rates may cause excessive scaling and/or burning of steel which means loss of production tonnages.

For metallurgical reasons (and economical ones) it is better to transfer the ingots as soon as possible after teeming to the soaking pits. The time from teeming to soaking pits is referred to as "Track Time". It makes sense that a hot ingot will be easier to reheat than a cold ingot and therefore will cut costs.

Heating facilities for ingots, slabs, billets and blooms are generally divided into two general classes:

(i) soaking pit furnaces (ingot and slabs)
(ii) reheating furnaces (slabs, bloom, billets).

Both of these must be constructed of materials that can withstand temperature levels from 1100°F to 2450°F, different material sizes and handling rates.

The common parts for all designs of furnaces are:

- heating chamber: an enclosure to contain material and retain heat;
- a hearth or support for the charge;
- facilities for development of heat to rise and fall to maintain furnace temperature;
- means for distribution of heat and removal of spent gases;
- means to add new ingots and remove readied ones.

5.2 Soaking Pits

There are various classifications of soaking pits which basically vary only by the way they circulate heat throughout the furnace.

Soaking pits generally have hearths ranging from 100 square feet to over 300 square feet. The normal operating temperature ranges from 2050°F to 2450°F with many of the furnaces having recuperators to recover heat losses.

Soaking pits are classified in various ways, including:

- regenerative;
- recuperative;
- bottom centre-fired;
- bottom two-way fired;
- top two-way fired;
- top one-way fired;
- electric.

In all soaking pits the bottoms are lined either with coke breeze, dolomite or magnesite to help heat the bottom of the ingots.

The main requirements of soaking pits are:

- uniform heating of all ingots in pit with no localized overheating of any ingot;
- heating rate equal to the ability of steel to safely absorb heat;
- sufficient holding capacity without overcrowding;
- low operating cost;
- control of furnace atmosphere;
- ability to duplicate heating practices;
- minimum expenditure of good ground space;
- minimum capital expenditure.

5.3 Reheating Furnaces

Reheating furnaces are used when slabs, billets and blooms must be reheated for further reduction (hot-working). They come in three types:

(i) batch

(ii) continuous - pusher type
- rotary hearth type
- walking-beam type
- roller hearth type

(iii) induction

Little more will be said of reheating furnaces other than in Section 13, Other Potential Applications.

6.0 The Soaking Pit Process

Any consideration of the efficiency of fuel use in the soaking pit process must look beyond the pit itself to realize the full savings potential. For this reason a complete analysis of the process is illustrated below in Figure 1.[1]

After teeming, or pouring, the ingot the process of solidification starts. When the solidified surface of the ingot is strong enough, the mold can be removed (time, t_m). Transport from the steel plant to the stripping bay significantly affects t_m.

After stripping, there is a period during which the ingot cools, t_n, and solidification continues. The ingot is then placed in the soaking pit with the object of reducing the temperature differences in the ingot and reaching an average temperature level such that the ingot can be rolled easily to a finished product with good properties, t_6. At the moment of actual rolling, the ingot has to be solidified completely.

The heating process in the soaking pit itself is illustrated in Figure 2.[1]

After charging the soaking pit, the temperature level of the pit is usually set, after which the fuel is supplied and combustion started. The maximum firing rate is then employed until the moment when the soaking pit wall has reached the temperature setpoint. This is followed by a period of adjustment, which lasts until the ingot surface has reached a sufficiently high equilibrium temperature. The fuel supply then remains practically constant and basically compensates for heat losses.

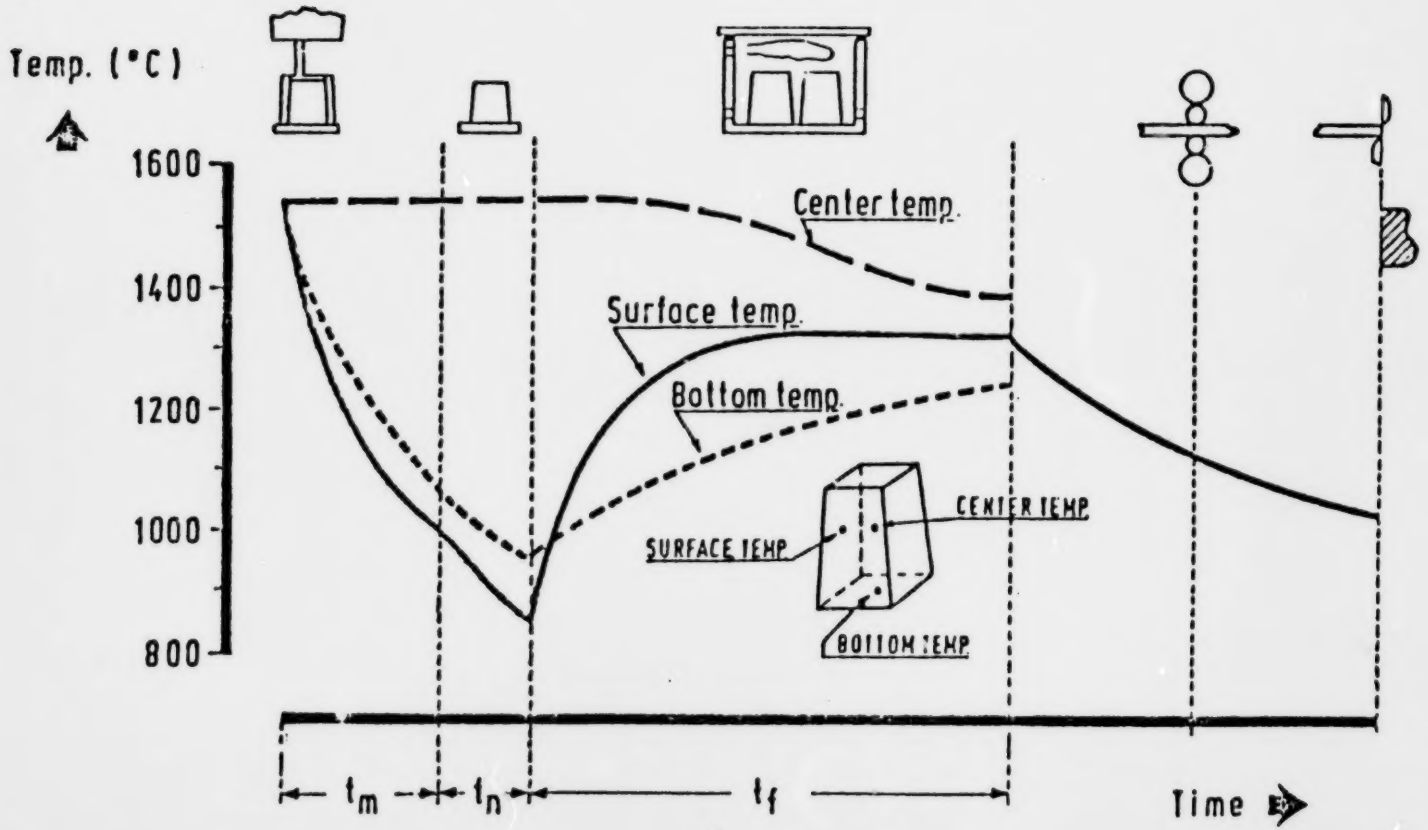


FIGURE 1 - MILL PROCESS ANALYSIS

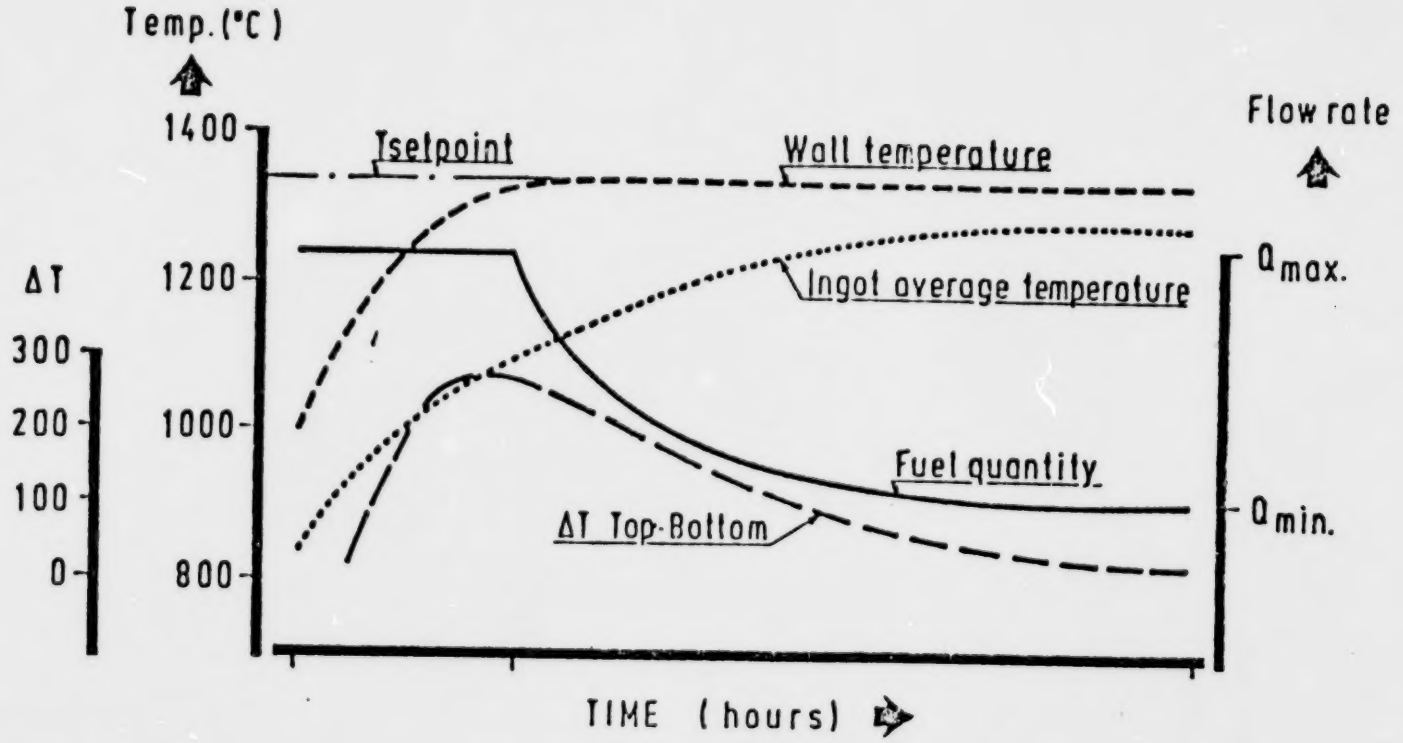


FIGURE 2 - SOAKING PIT TEMPERATURE PROFILE

An initial high average ingot temperature shortens the heating up period and contributes to a lower fuel consumption.

The heating process will differ for each type of soaking pit, type of ingot, etc. A generalized heat balance, which illustrates the approximate efficiency of the process, is shown in Figure 3.[1] The heat input consists of approximately 85% fuel, 12% combustion air and 3% from the oxidation of the ingot surface. Only 32% of the heat input contributes to ingot heating. The heat content of the waste gases represents 58% of the heat input with 10% lost through the pit walls and covers.

Figure 4[2] shows a typical soaking pit which essentially is a batch type furnace comprised of a refractory box, a removable cover, and a combustion system. In operation, the pit is charged with ingots, the control is set and the ingots are heated to whatever temperature the product specifications call for.

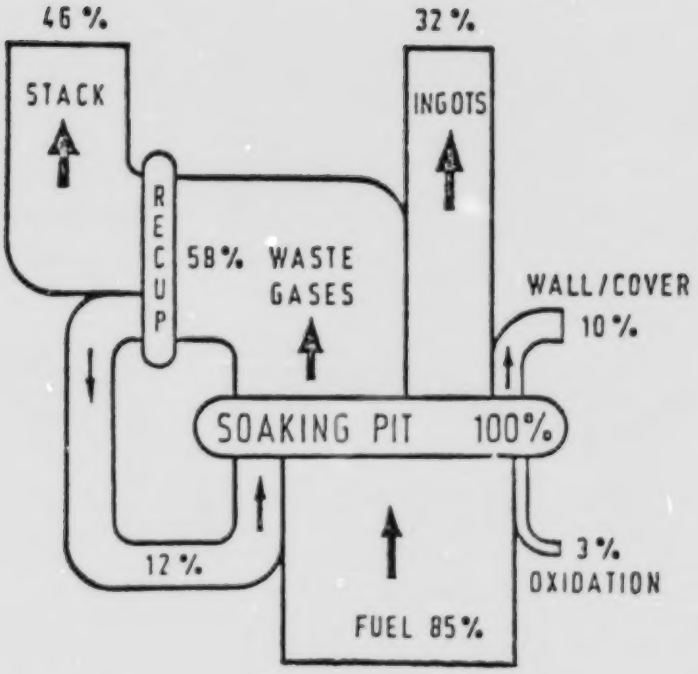


FIGURE 3 - GENERIC SOAKING PIT HEAT BALANCE

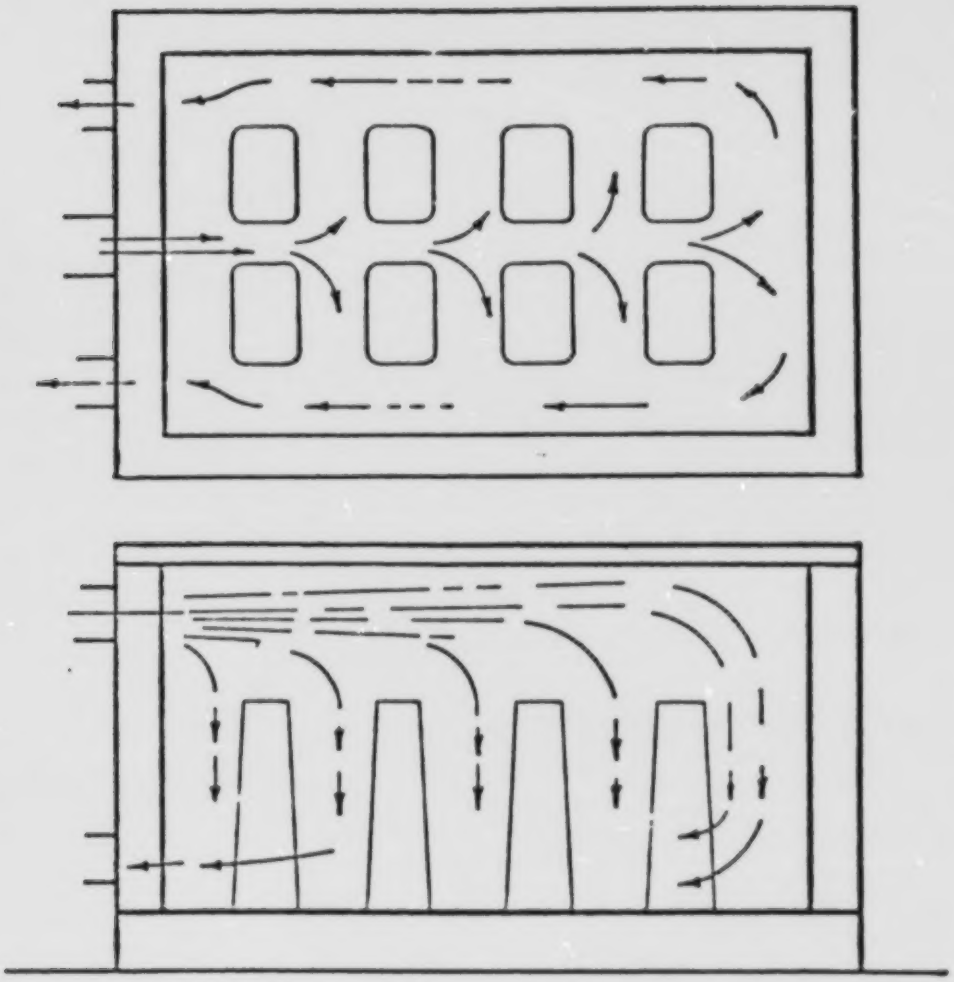


FIGURE 4 - TYPICAL SOAKING PIT

7.0 Pit and Equipment Description

The soaking pit specifications at the IPSCO INC. Regina plant are:

- one-way top fired (4 of 13 recuperative)
- 13 in number
  - 9 at 28×10^6 BTU/H maximum firing rate and 200 ft^2
  - 4 at 30×10^6 BTU/H maximum firing rate and 250 ft^2 (recuperators)
- fuel natural gas, oil standby
- recuperators metallic radiation type

The associated major equipment materials list for one of the four more recent recuperative pits is listed in Appendix D.

Installed equipment on the nine non-recuperative pits is similar to those listed in Appendix D less the recuperator and related equipment.

The computer control system provided has both controlling and monitoring functions. All thirteen pits can be controlled automatically from the consul, pit temperatures can be reset, etc. The monitoring functions are used to tract pit performance and for record keeping.

8.0 Test Data

All combustion efficiency measurements were provided by Western Combustion Ltd., a subconsultant retained by Keen Engineering Co. Ltd. for this work. A copy of the report submitted by Western Combustion is enclosed as Appendix E. The test equipment used is listed in their report.

Soaking pit conditions reported were obtained from the computerized control and monitoring system described earlier. Some reprogramming of the computer had to be undertaken in order to obtain temperature data relative to recuperator performance.

Other information and data contained herein was obtained from IPSCO INC. personnel too numerous to mention.

Table 1 indicates the data relative to a comparison of a recuperative and non-recuperative pit having very similar charges. The pit rear wall temperature and gas flow for each pit is illustrated in Graph 1. The contents of each pit, taken from the soaking pit inventory, is recorded in Table 2.

Table 3 indicates the data obtained, again in comparing a recuperative and a non-recuperative pit with a similar charge. In this case the monitoring computer had been reprogrammed to record recuperator flue gas in and out, and air preheat temperatures. The rear wall pit temperatures and fuel flows are illustrated in Graph 2, the recuperator temperature profiles in Graph 3. The soaking pit inventory in the pits is recorded in Table 4.

Table 5 indicates data obtained on a recuperative pit in an effort to verify results of the previous test. The rear wall

pit temperature and fuel flow are illustrated in Graph 4, the recuperator temperature profiles in Graph 5.

Table 6 indicates the data provided by Western Combustion Services Ltd with respect to combustion efficiencies. One recuperative pit and one non-recuperative pit were picked at random.

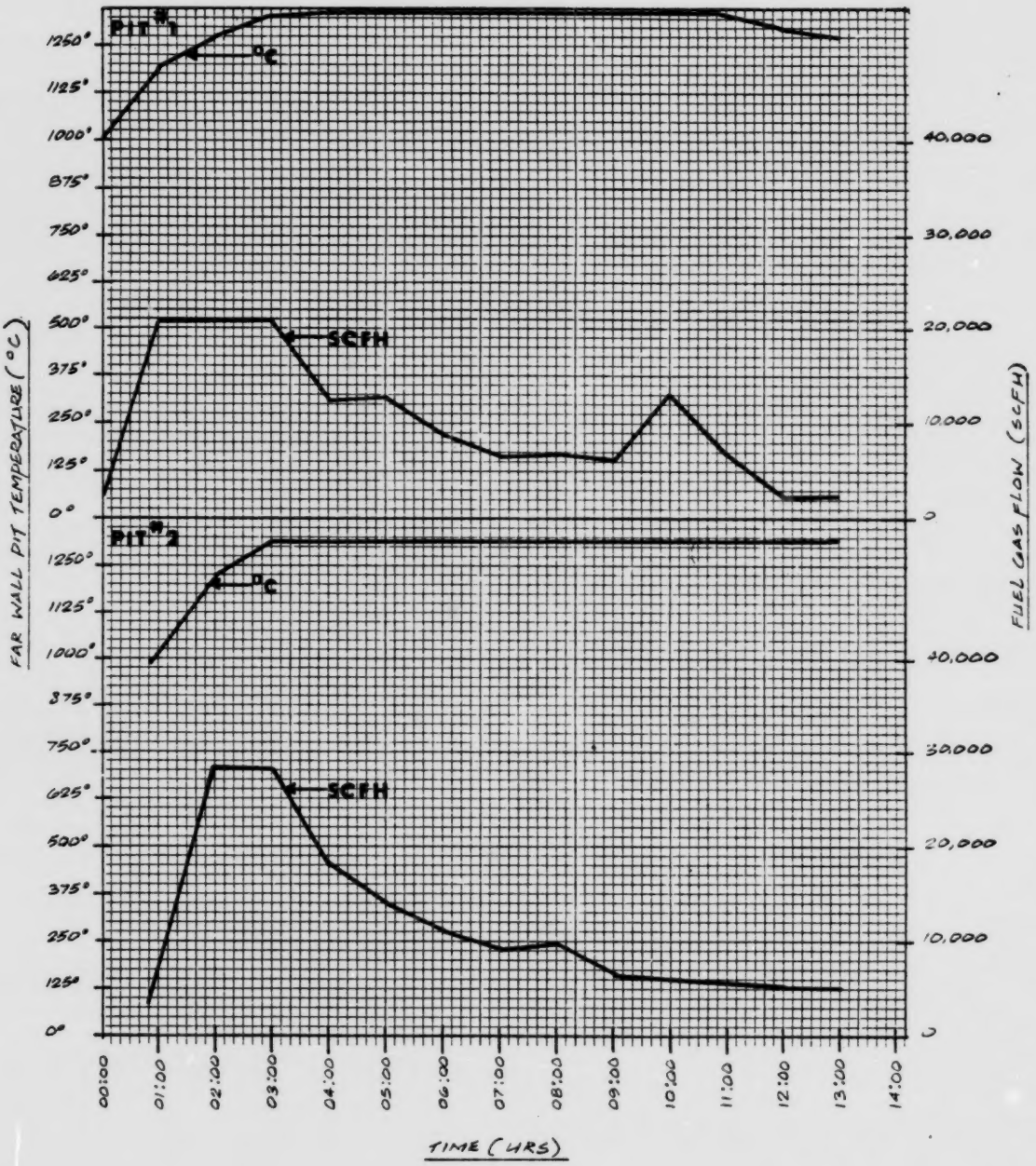
TABLE 1

TEST #1 DATA

Time	Pit #1 (no recuperator)			Pit #11 (recuperator)		
	Far Wall Pit Temperature (°C)	Combustion Air Flow (SCFH)	Fuel Gas Flow (SCFH)	Far Wall Pit Temperature (°C)	Combustion Air Flow (SCFH)	Fuel Gas Flow (SCFH)
00:00	1017.17	38667.96	2475.55			
00:10	997.52	38583.47	2476.08			
00:20	1112.79	199365.87	20243.62			
00:30	1153.23	199596.00	20193.35			
00:40	1177.19	199252.43	20183.38			
00:50	1194.79	199399.31	20191.53	990.18	123718.68	3658.32
01:00	1209.04	199691.56	20226.34	829.57	121624.93	3649.82
01:10	1222.24	199361.87	20219.08	914.51	308592.50	28178.14
01:20	1233.99	199060.56	20202.58	1088.10	314399.00	28554.26
01:30	1242.00	199254.18	20209.40	1141.43	312227.00	28647.06
01:40	1253.92	198600.62	20208.73	1175.02	313788.06	28663.47
01:50	1265.20	198665.18	20168.42	1201.93	312785.75	28668.99
02:00	1276.12	197749.37	20099.91	1222.40	312970.31	28684.70
02:10	1285.32	198183.43	20057.04	1242.07	312163.50	28468.88
02:20	1297.55	197959.50	20029.50	1259.65	311078.50	28523.71
02:30	1309.00	197873.06	20032.05	1274.56	312214.31	28332.75
02:40	1318.99	198091.81	19983.02	1290.40	312399.81	28543.17
02:50	1328.68	198454.43	19982.18	1304.47	311479.00	28377.34
03:00	1336.81	198431.93	20013.10	1317.20	312492.56	28308.83
03:10	1342.49	197397.43	19712.29	1324.14	273581.18	24997.35
03:20	1344.77	178395.93	17842.15	1321.61	249459.31	22597.43
03:30	1342.51	155080.00	15530.09	1320.92	229694.25	20938.71
03:40	1340.73	146814.81	14713.98	1320.82	216271.68	19623.47
03:50	1342.78	164851.06	16443.54	1320.62	202653.93	18495.87
04:00	1343.97	128177.06	12747.46	1319.76	196627.75	18056.35
04:10	1341.80	98443.56	9832.36	1320.46	188529.50	17308.70
04:20	1338.68	87641.25	8786.70	1320.46	178054.25	16187.71
04:30	1336.49	128856.87	12906.40	1320.28	172015.50	15716.89
04:40	1340.57	137527.87	13780.30	1320.36	166218.31	15151.33
04:50	1340.03	130276.56	13039.94	1320.35	158425.81	14375.37
05:00	1340.74	129380.31	12874.84	1320.46	152316.37	13912.21
05:10	1340.46	121611.75	12113.32	1320.46	150330.12	13523.66
05:20	1340.90	114348.62	11445.42	1320.12	143196.93	13009.29
05:30	1341.09	101574.25	10133.69	1319.87	136556.75	12426.14
05:40	1341.28	89144.68	8890.79	1320.10	131343.62	11935.97
05:50	1340.38	81195.18	8113.88	1320.12	125722.25	11330.27
06:00	1342.19	92258.93	9123.43	1320.09	121922.81	11269.22
06:10	1340.74	71579.43	7137.69	1320.10	114802.18	10525.48
06:20	1340.13	71280.62	7137.28	1320.01	113349.81	10345.49
06:30	1340.18	66161.68	6608.85	1320.46	110980.87	10006.16
06:40	1338.09	73997.00	7359.37	1320.10	107912.81	9742.26
06:50	1340.82	67502.18	6797.39	1320.16	104306.50	9417.21

TABLE 1 - *Continued*

Time	Pit #1 (no recuperator)			Pit #11 (recuperator)		
	Far Wall Pit Temperature (°C)	Combustion Air Flow (SCFH)	Fuel Gas Flow (SCFH)	Far Wall Pit Temperature (°C)	Combustion Air Flow (SCFH)	Fuel Gas Flow (SCFH)
07:00	1339.55	66823.87	6665.85	1319.97	101529.18	9067.15
07:10	1339.48	67872.37	6723.05	1319.94	99002.25	8808.17
07:20	1340.03	66589.12	6712.91	1320.18	93761.25	8566.36
07:30	1340.16	67109.87	6695.26	1319.76	92187.50	8499.19
07:40	1340.76	67297.87	6613.30	1320.12	89714.56	8264.92
07:50	1338.29	66266.56	6764.63	1320.10	88587.37	8139.97
08:00	1341.08	69262.06	6827.66	1319.49	109583.87	9729.50
08:10	1340.06	64293.64	6392.05	1320.38	82472.56	7368.01
08:20	1339.78	63401.58	6333.37	1320.36	82015.62	7385.28
08:30	1339.90	62526.47	6230.68	1320.18	77783.43	7101.52
08:40	1338.97	65117.49	6431.44	1319.78	73773.62	6916.33
08:50	1341.24	90094.06	8980.73	1320.11	72525.06	6755.04
09:00	1340.73	62616.25	6250.54	1320.20	71742.62	6437.71
09:10	1340.02	62996.39	6329.79	1320.11	69542.62	6306.84
09:20	1340.38	63008.67	6329.88	1320.16	68763.56	6187.52
09:30	1289.28	76956.31	2506.37	1320.11	66994.68	6179.29
09:40	1138.00	198069.37	19855.76	1320.10	66445.75	5958.83
09:50	1321.05	199905.68	19940.48	1320.15	65842.18	5942.54
10:00	1352.32	132378.50	13148.16	1319.94	64571.68	5822.39
10:10	1343.45	88608.18	8905.18	1320.11	64277.03	5770.06
10:20	1340.06	85443.18	8499.53	1320.03	61768.68	5646.60
10:30	1340.98	77478.31	7686.27	1320.24	62689.63	5599.88
10:40	1340.13	74417.37	7465.68	1319.86	61200.28	5511.59
10:50	1339.68	69916.56	7047.10	1320.01	59798.52	5476.71
11:00	1339.68	70623.50	7046.41	1319.77	61630.10	5440.11
11:10	1340.75	63347.11	6383.84	1320.31	61576.37	5637.08
11:20	1322.21	37396.25	2333.44	1320.10	60719.56	5356.95
11:30	1307.79	37454.52	2312.12	1320.12	61747.22	5373.62
11:40	1299.93	36969.13	2312.91	1320.29	61240.51	5313.10
11:50	1292.62	36782.31	2308.30	1320.10	60885.31	5260.28
12:00	1292.57	35770.17	2303.65	1319.82	60370.64	5190.87
12:10	1300.34	35690.19	2314.10	1319.74	60690.60	5211.45
12:20	1286.80	35885.63	2311.10	1319.84	61391.41	5207.44
12:30	1281.02	36002.53	2314.28	1320.10	61274.10	5079.73
12:40	1274.04	35956.73	2311.56	1319.87	61049.03	4978.18
12:50	1270.98	35949.68	2314.01	1320.12	60434.39	4942.66
13:00	1270.05	36022.36	2307.46	1320.11	61492.06	4932.84
13:10	1268.83	35947.86	2313.93	1320.10	61168.43	4908.55



GRAPH 1

TEST #1 FUEL PROFILE

TABLE 2

TEST #1 PIT INVENTORY

	Pit #1 (no recuperator)		Pit #11 (recuperator)
Heat No.	508249	508248	508253
No. of Ingots	8	1	9
Ingot Size	25 x 45		25 x 45
Specification	651.51		651.51
Width and Gauge	104 x 38.7		104 x 38.7
Finish Teem	02:20		10:11
Charge Time	09:49		16:15

TABLE 3

TEST #2 DATA

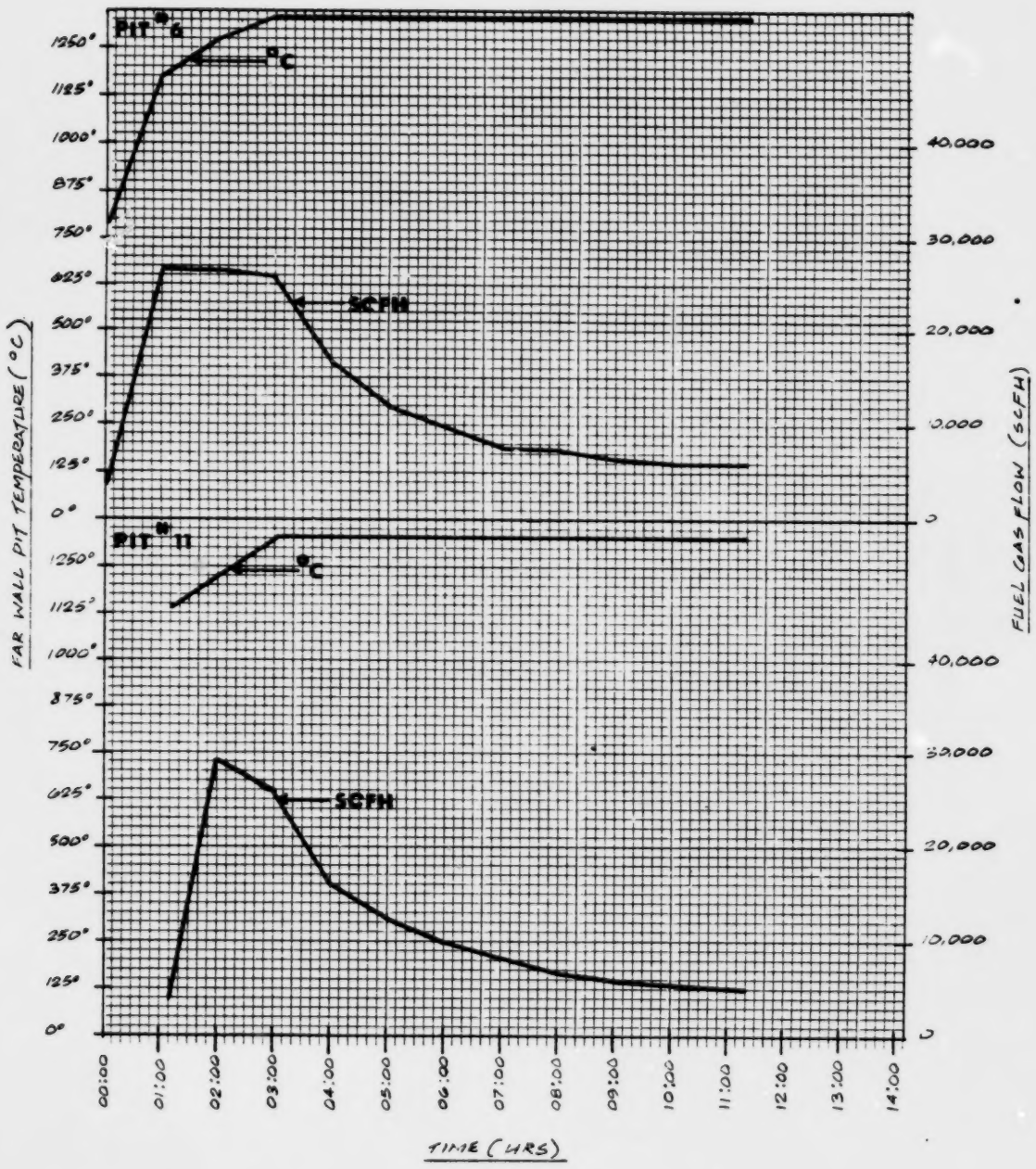
Time	Pit #6 (no recuperator)			Pit #11 (recuperator)					
	Far Wall Pit Temperature (°C)	Combustion Air Flow (SCFH)	Fuel Gas Flow (SCFH)	Far Wall Pit Temperature (°C)	Combustion Air Flow (SCFH)	Fuel Gas Flow (SCFH)	Recu-perator in (°C)	Recu-perator out (°C)	Air Preheat (°C)
00:00	832.94	67039.25	3304.76						
00:10	777.18	67628.75	3327.15						
00:20	871.01	265224.18	26662.39						
00:30	1060.78	264999.81	26738.91						
00:40	1116.95	264578.18	26743.16						
00:50	1150.29	264844.75	26749.82						
01:00	1176.64	263844.81	26766.89						
01:10	1198.77	264127.00	26745.59	1112.45	85606.06	3831.83	639.33	449.89	396.89
01:20	1216.91	263230.43	26714.85	898.52	83002.37	3783.32	600.55	384.93	376.58
01:30	1233.21	263921.12	26737.83	1054.25	314183.49	28301.49	717.91	499.70	316.98
01:40	1248.23	264771.18	26692.60	1153.23	315294.93	28686.98	755.26	537.59	333.14
01:50	1261.12	263921.00	26656.50	1194.96	314325.62	28611.71	777.00	558.32	348.15
02:00	1273.84	261793.93	26664.25	1223.32	315649.62	28769.06	795.50	572.98	359.47
02:10	1285.59	262185.93	26493.62	1245.37	311605.37	28226.50	803.30	576.92	366.39
02:20	1297.00	261776.43	26676.95	1263.67	314807.37	28565.53	797.36	578.35	369.30
02:30	1307.35	263294.06	26626.03	1282.70	313321.06	28682.37	808.14	584.44	372.94
02:40	1318.48	262205.75	26638.16	1302.01	313387.00	28832.37	785.87	572.27	362.02
02:50	1327.98	262980.87	26340.76	1318.97	313816.37	28613.58	788.83	574.06	355.09
03:00	1330.98	254867.50	25439.66	1322.99	282263.50	25732.58	764.45	559.40	355.09
03:10	1332.84	227445.25	22659.32	1321.54	263688.68	23862.57	801.82	573.70	375.49
03:20	1331.89	207361.37	20660.24	1321.08	242666.06	22054.42	798.47	565.12	386.02
03:30	1331.03	195451.56	19755.98	1321.29	224852.56	20291.42	798.47	559.04	390.73
03:40	1331.35	187455.43	18690.64	1320.78	209402.50	18991.30	793.28	551.17	395.08
03:50	1331.13	174350.81	17606.63	1320.78	187595.25	17311.73	795.50	542.95	397.61
04:00	1331.60	165336.00	16389.18	1320.88	175968.31	15979.62	755.99	547.24	397.25
04:10	1331.18	153329.68	15247.92	1320.34	169089.31	15462.20	728.13	528.66	388.19
04:20	1331.18	142900.06	14509.67	1320.46	164297.12	14826.19	749.01	522.58	390.37
04:30	1331.05	138417.00	14039.69	1320.24	154982.18	14044.82	767.77	521.87	396.89

TABLE 3 - *Continued*

Time	Pit #6 (no recuperator)			Pit #11 (recuperator)					
	Far Wall Pit Temperature (°C)	Combustion Air Flow (SCFH)	Fuel Gas Flow (SCFH)	Far Wall Pit Temperature (°C)	Combustion Air Flow (SCFH)	Fuel Gas Flow (SCFH)	Recu-perator in (°C)	Recu-perator out (°C)	Air Preheat (°C)
04:40	1331.17	147853.87	14850.50	1320.46	149430.12	13360.47	755.62	526.16	401.95
04:50	1331.85	125697.43	12699.77	1320.32	142188.81	12858.47	760.40	521.87	402.68
05:00	1330.92	118845.50	12053.59	1320.12	139649.12	12462.75	747.18	520.08	405.21
05:10	1330.82	113960.31	11443.16	1323.04	140020.93	12605.83	729.96	510.43	401.59
05:20	1330.85	109728.62	10955.51	1320.29	125900.00	11361.70	726.67	497.91	400.15
05:30	1330.47	103718.31	10523.53	1320.58	119760.62	10846.50	742.04	487.89	400.51
05:40	1330.35	103149.75	10442.70	1320.24	119545.62	10728.26	745.34	488.61	401.59
05:50	1330.47	98536.37	9864.76	1320.26	114187.31	10366.74	727.77	483.24	402.32
06:00	1330.47	96217.87	9698.04	1320.17	110209.00	10044.68	743.14	480.37	404.13
06:10	1331.21	103156.18	10191.92	1320.46	108939.25	9740.32	732.16	477.15	405.21
06:20	1331.14	88576.50	8931.05	1320.10	105201.81	9498.61	730.69	476.79	406.66
06:30	1330.58	86691.87	8834.98	1320.07	99787.87	9125.80	735.45	472.49	408.46
06:40	1331.04	78583.56	7883.32	1320.26	97261.12	8792.69	740.94	469.98	410.99
06:50	1330.15	79812.75	7958.12	1320.11	94722.37	8685.79	735.82	465.32	412.80
07:00	1330.15	79613.50	7799.06	1320.45	91722.50	8288.56	733.99	462.81	414.24
07:10	1330.44	76238.12	7780.62	1320.15	88086.87	8103.16	761.88	458.51	415.32
07:20	1330.47	76983.31	7625.08	1320.28	85746.87	7761.41	732.89	456.35	416.05
07:30	1330.50	74275.68	7465.44	1319.69	86856.50	7809.40	729.23	456.71	416.77
07:40	1330.48	76940.50	7443.96	1320.46	81946.37	7599.69	760.40	454.56	417.13
07:50	1330.47	74112.25	7385.41	1320.19	79611.93	7183.84	742.41	452.76	417.13
08:00	1333.37	73575.37	7507.23	1320.41	73354.18	6753.46	729.60	448.81	417.13
08:10	1330.50	73061.87	7104.33	1319.97	71501.50	6478.61	730.33	447.01	417.49
08:20	1330.67	69647.37	6474.28	1320.19	70018.06	6299.75	747.91	446.65	418.93
08:30	1330.15	70110.25	6501.64	1320.14	67245.87	6043.12	747.54	446.30	418.93
08:40	1330.50	70199.12	6432.11	1319.96	66420.56	5986.90	741.31	445.22	420.38
08:50	1330.14	69665.81	6548.69	1319.94	64837.52	5914.79	747.54	444.14	421.10
09:00	1330.47	71029.12	6428.68	1320.11	65437.88	5838.71	733.99	443.06	422.18
09:10	1330.48	69924.00	6241.00	1319.77	63100.79	5698.80	740.94	443.06	423.26
09:20	1330.46	68268.62	6146.35	1322.99	75386.75	6525.43	745.34	448.81	425.42
09:30	1330.39	69606.50	6096.67	1320.28	63141.03	5392.28	762.98	450.25	427.22

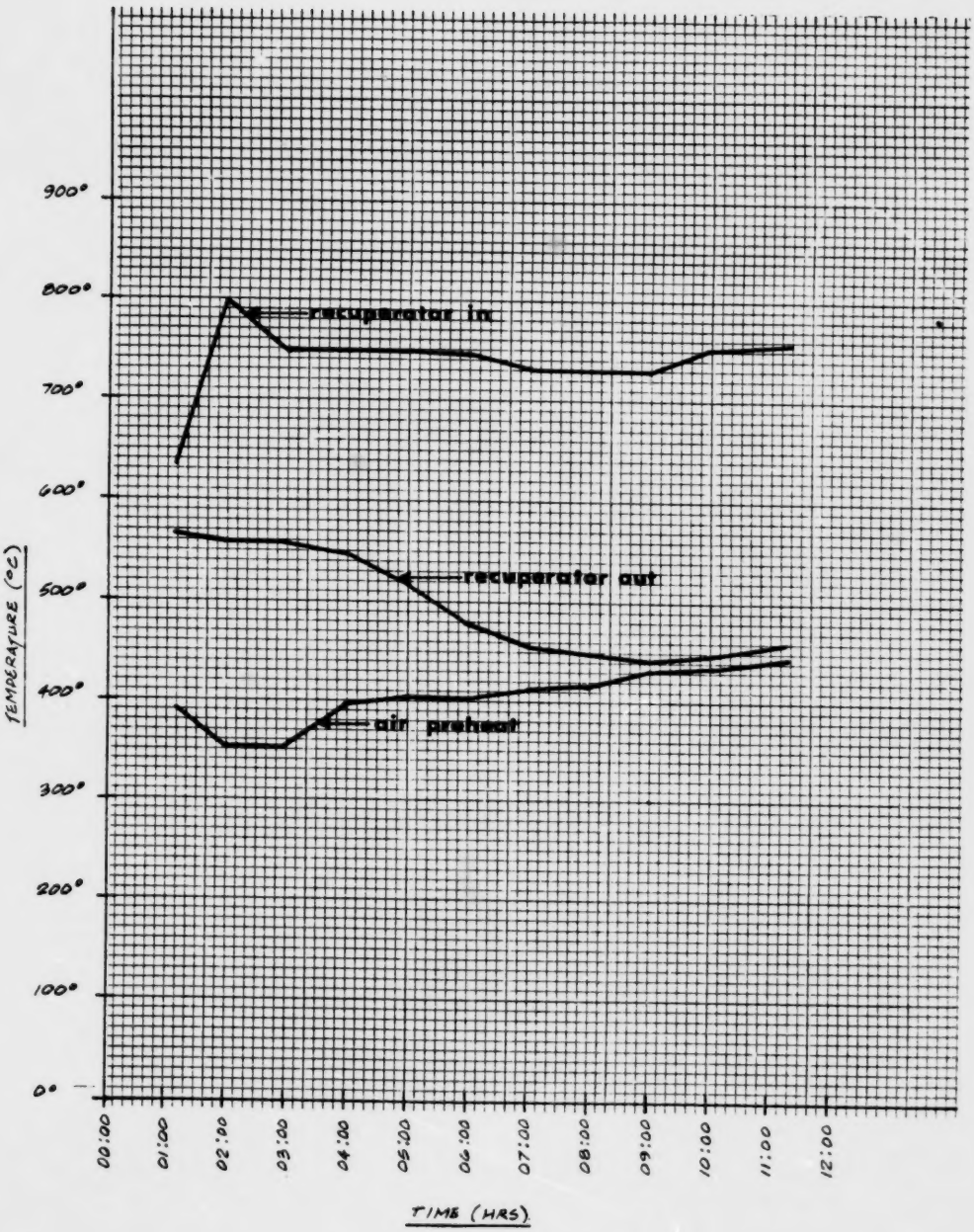
TABLE 3 - *Continued*

Time	Pit #6 (no recuperator)			Pit #11 (recuperator)					
	Far Wall Pit Temperature (^{o}C)	Combustion Air Flow (SCFH)	Fuel Gas Flow (SCFH)	Far Wall Pit Temperature (^{o}C)	Combustion Air Flow (SCFH)	Fuel Gas Flow (SCFH)	Recu-perator in (^{o}C)	Recu-perator out (^{o}C)	Air Preheat (^{o}C)
09:40	1330.10	70439.31	6211.03	1320.04	63595.07	5490.50	759.67	450.25	429.75
09:50	1330.44	70531.00	6183.08	1320.11	63007.33	5341.79	753.42	452.04	432.99
10:00	1331.47	70482.12	6123.54	1320.34	63184.36	5373.66	754.89	453.84	435.51
10:10	1330.32	71616.62	6110.19	1320.11	63216.45	5165.03	756.36	454.92	437.67
10:20	1330.39	70694.25	6074.28	1320.27	62729.08	5138.43	768.88	455.63	439.46
10:30	1330.33	70298.93	5969.26	1249.03	76783.75	4009.28	778.84	489.32	435.15
10:40	1330.31	71437.81	5846.46	1318.65	79337.87	7312.22	776.26	472.13	446.65
10:50	1330.13	72390.12	5904.90	1320.35	64055.52	5460.19	774.04	462.81	441.62
11:00	1330.37	71320.37	5848.89	1321.87	63988.58	4822.45	751.21	463.53	443.78
11:10	1330.07	70500.37	5997.05	1320.16	64249.82	4982.22	774.04	462.81	444.14
11:20	1330.45	70701.12	6025.46	1320.22	63439.64	4882.82	761.14	463.53	445.58



GRAPH 2

TEST #2 FUEL PROFILE



GRAPH 3

TEST #2 RECUPERATOR PROFILE

TABLE 4

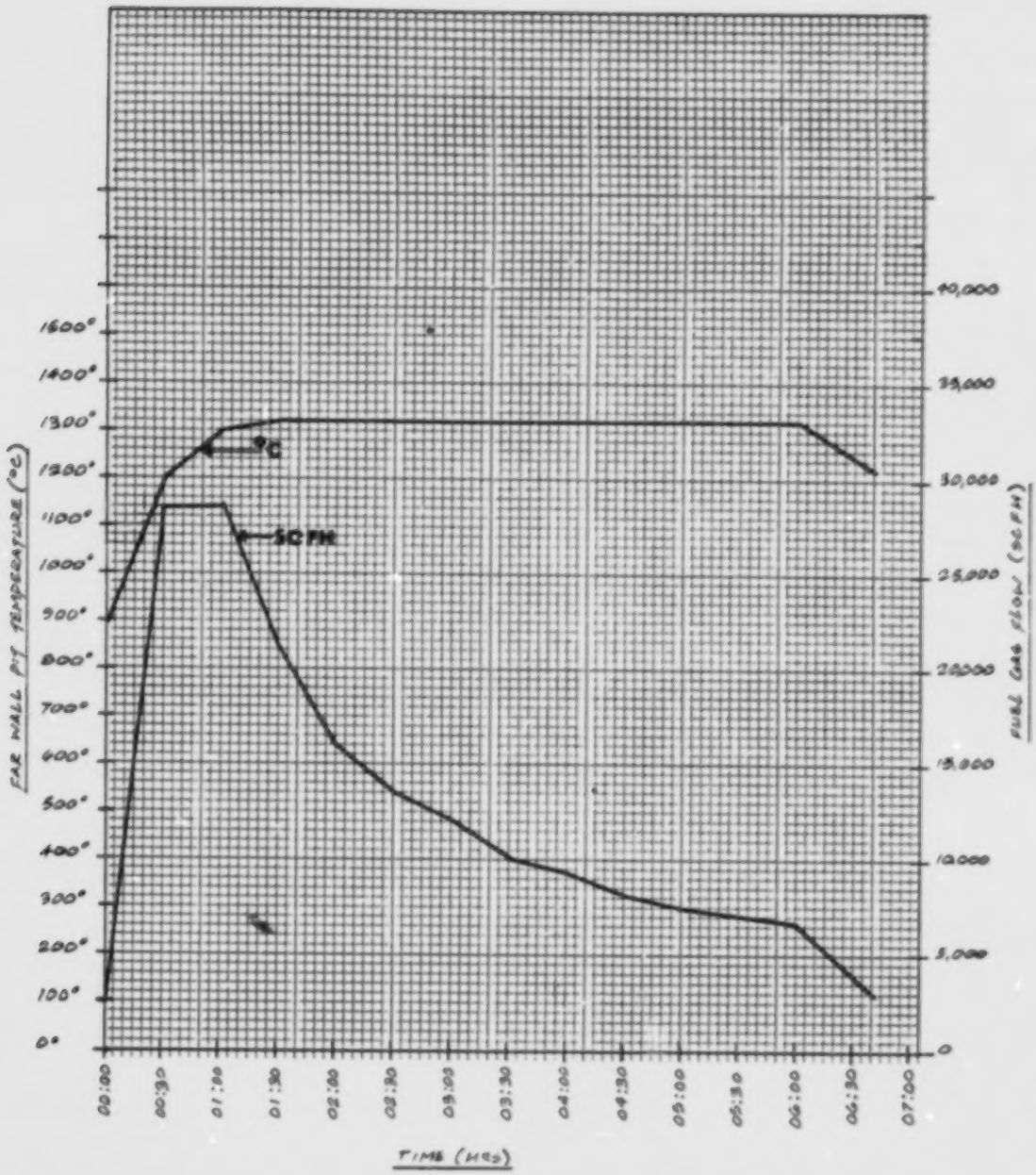
TEST #2 PIT INVENTORY

	Pit #6 (no recuperator)	Pit #11 (recuperator)
No. of Ingots	7	7
Ingot Size	27 x 57	27 x 57
Specification	35101	35101
Width and Gauge	155 x 46	155 x 46
Finish Teem	0238	-
Charge Time	0840	0511
Estimated Rolling Time	2000	1700

TABLE 5

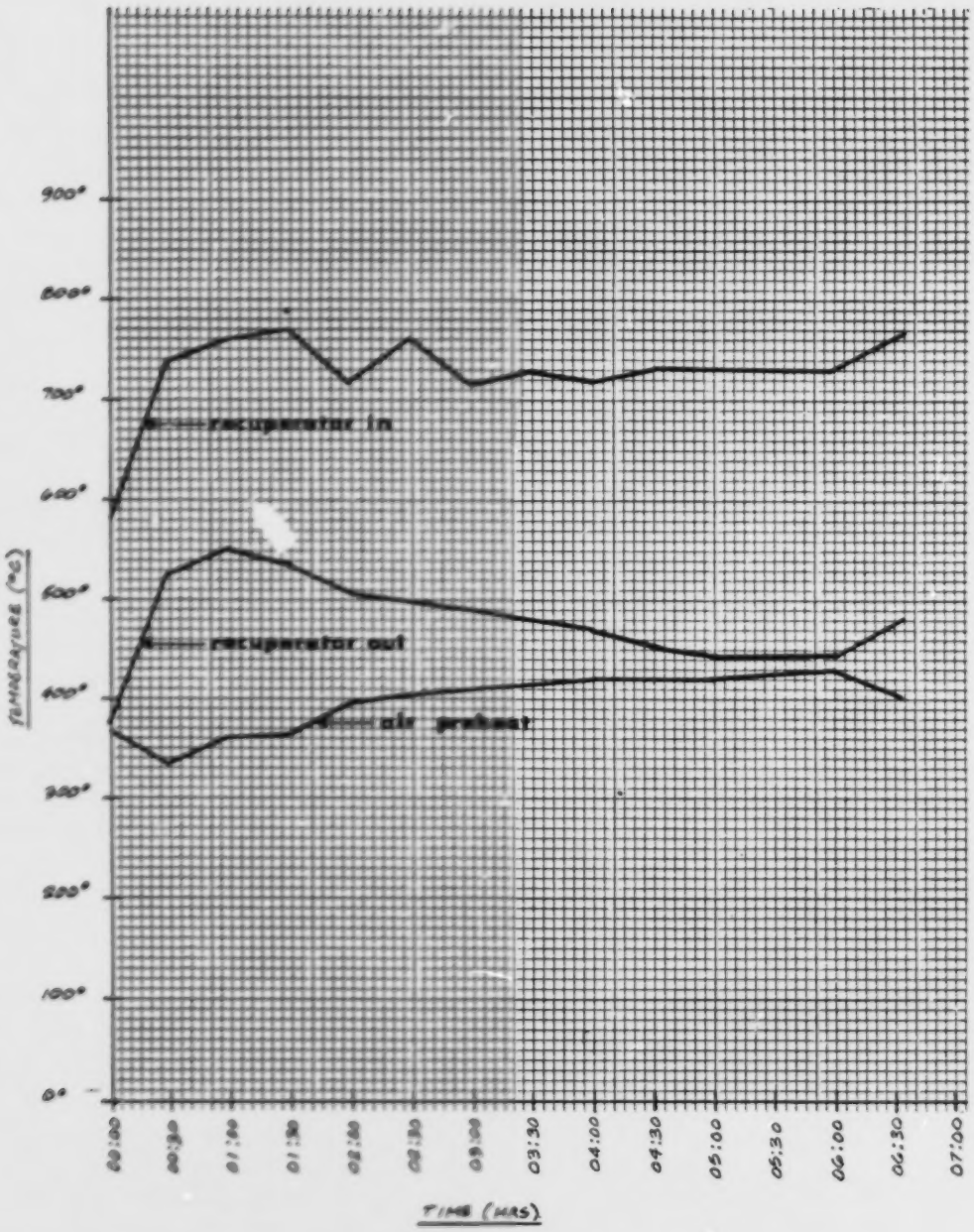
TEST #3 DATA

Time	Pit #11 (recuperator)					
	Far Wall Pit Temperature (°C)	Combustion Air Flow (SCFH)	Fuel Gas Flow (SCFH)	Recu-perator in (°C)	Recu-perator out (°C)	Air Preheat (°C)
00:00	902.36	112819.37	2656.78	580.50	374.76	366.75
00:10	949.46	114080.75	2685.71	636.10	376.94	339.00
00:20	1120.63	308935.37	28084.92	700.07	472.49	313.30
00:30	1201.99	310349.93	28481.52	742.77	523.66	335.34
00:40	1240.28	309834.37	28513.94	769.61	545.81	352.90
00:50	1276.76	309641.62	28628.13	760.04	550.82	361.29
01:00	1303.07	309841.50	28525.83	761.14	549.39	362.75
01:10	1321.64	303258.56	27540.50	763.72	546.89	360.92
01:20	1322.89	261616.81	23847.45	697.89	538.31	356.91
01:30	1321.93	233011.25	21058.87	768.88	534.02	366.75
01:40	1321.54	206735.75	18731.19	772.93	524.37	376.21
01:50	1320.84	189529.37	17156.62	759.67	514.01	385.29
02:00	1320.33	174017.62	15977.22	714.63	507.93	393.63
02:10	1320.47	166050.43	14976.64	723.75	506.85	400.51
02:20	1320.46	156581.87	14149.90	741.68	502.92	403.40
02:30	1320.46	151554.12	13617.33	761.14	497.55	404.85
02:40	1320.46	145836.18	13173.89	712.08	497.55	406.29
02:50	1319.92	139018.43	12545.91	715.00	492.90	408.46
03:00	1319.76	131497.75	12047.22	716.09	489.32	409.91
03:10	1320.46	126964.93	11543.91	719.74	486.82	411.71
03:20	1320.46	121473.00	11019.26	728.13	483.95	413.88
03:30	1319.92	111410.81	10208.29	728.13	478.94	416.77
03:40	1320.21	106392.25	9930.36	723.02	474.64	417.85
03:50	1320.10	102707.43	9493.21	723.02	471.42	419.29
04:00	1319.83	101052.18	9354.81	720.83	468.55	420.01
04:10	1323.08	92767.68	8491.30	749.38	474.28	415.32
04:20	1320.23	92707.81	8442.95	727.04	463.89	420.74
04:30	1320.10	90926.31	8155.74	728.87	457.43	421.10
04:40	1319.79	90185.93	8059.00	733.25	451.68	421.46
04:50	1320.25	84997.50	7806.10	729.96	450.25	422.18
05:00	1320.18	85750.25	7655.80	729.96	447.01	422.90
05:10	1320.11	79286.25	7323.83	728.13	444.86	423.98
05:20	1320.39	78340.68	7138.12	736.18	441.98	424.70
05:30	1320.10	78409.31	7067.84	732.52	443.06	425.78
05:40	1320.03	75793.18	6850.00	735.82	443.78	428.67
05:50	1320.18	73155.31	6560.66	740.21	443.06	430.11
06:00	1320.22	72327.12	6621.89	733.25	443.06	430.11
06:10	1321.01	65209.00	6068.37	720.47	450.25	425.42
06:20	1293.30	118826.00	10725.41	767.40	463.53	413.16
06:30	1310.33	116267.18	2740.16	721.56	493.26	403.04
06:40	1221.27	118256.31	2812.63	668.55	482.16	402.68



GRAPH 4

TEST #3 FUEL PROFILE



GRAPH 5

TEST #3 RECUPERATOR PROFILE

TABLE 6

COMBUSTION TEST DATA

Readings	$\%O_2$	^oC Flue Gas After Recup	^oC Flue Gas Before Recup	ft^3/hr Gas Flow	Preheat Combustion Air
Pit #12 (recuperator)					
1	2.50	577	858	29,700	382°C
2	2.50	584	866	29,900	381°C
3	3.75	520	750	14,340	407°C
4	4.00	519	757	13,340	417°C
5	4.25	515	750	11,760	420°C
6	4.50	493	747	4,568	417°C
7	4.50	473	749	7,399	430°C
Pit #8 (no recuperator)					
High	4.00	-	975	25,000	-
Middle	6.50	-	963	15,000	-
Low	7.50	-	947	5,000	-

9.0 Data Analysis

9.1 General

In response to the scope of work outlined in Section 3, the first objective of our analysis was to determine the potential fuel savings in soaking pit operation offered by:

(i) flue gas to combustion air recuperators;

(ii) combustion improvements.

In a later section the discussion will be extended briefly to other possible energy savings in soaking pits and heat recovery in reheat furnaces.

9.2 Computations Performed

The test data obtained on the pits from the computer control and monitoring system was processed using a micro-computer and spreadsheet program to derive the required fuel use and/or savings figures. In all cases readings were taken once every ten minutes and assumed to be the average figure for that period. Three simple types of processing were performed.

(i) Pit Fuel Consumption

Recorded fuel data, which was recorded as standard cubic feet per hour (SCFH) was converted to actual consumption (cubic feet) in the ten minute period. The ten minute period consumptions were then accumulated to give the total consumption for the period under study. The total gas consumption to reach pit temperature set point and from then until the end of the study period are highlighted. Where two pits are compared in a test the period from reaching set point to the end of the recorded period is the same.

(ii) Air Preheat Energy Recovered

Combustion air flow which was recorded as standard cubic feet per hour (SCFH) was converted to the flow of air in cubic feet in that ten minute period. The air preheat temperature which was recorded in degrees Celsius was converted to a temperature rise in degrees Fahrenheit assuming a 20°C ambient temperature.

From the above the energy added to the combustion air for each ten minute period was computed and the individual periods totaled.

(iii) Air Preheat Fuel Savings

The figures computed in the previous two spreadsheets were combined and compared to give the percentage fuel savings provided by recuperation for each ten minute period and the complete study period. The bottom righthand figure thus represents the overall percentage saving for the study period. The percentage saving was calculated by dividing the air preheat energy saving by the total of the actual fuel consumption and the preheat saving. The third "input" energy provided by oxidation, as noted in Section 6, was not considered.

9.3 Computation Interpretation

The results of the computations outlined in 9.1 above, when performed on the data reproduced in Section 8, are enclosed over in Tables 7 to 15.

(i) Test #1

Test #1 was our first attempt to obtain data on the soaking pit process. At the time of the test the only data recorded by the monitoring system, which related to fuel use, was pit temperature and gas consumption. Other figures such as combustion air and flue gas temperatures could be called up on-line but were not recorded.

Our thought at this point was that a comparison of the fuel consumed, by a recuperative (#11) and a non-recuperative (#1) pit, over a set period for a similar ingot load would provide us with an estimate of fuel savings.

As can be seen from Tables 7 and 8 this was not the case. In fact for the test period both pits consumed very similar amounts of fuel in reaching set point. However, the non-recuperative pit consumed 14% less energy from set point to the end of the study period which in both cases was a ten hour period. Thus this test indicates a lower total fuel consumption for the non-recuperative pit.

In view of the difficulty of interpreting this result a second similar test was carried out.

(ii) Test #2

For test #2 the monitoring system was reprogramed to record combustion air preheat and flue gas temperatures.

TABLE 7

TEST #1 - PIT #1 FUEL CONSUMPTION

FUEL11 J91

TEST #1 : PIT #1 : 13 MARCH 1985 PIT FUEL CONSUMPTION

TIME	BURNER GAS CONSUMPTION RECORDED (SCFH)	IN 10min (SCF)	ACCUMULATED (SCF)		
17:32	2476	413	413		
17:42	2476	413	825		
17:52	20244	3374	4199		
18:02	20193	3366	7565		
18:12	20183	3364	10929		
18:22	20192	3365	14294		
18:32	20226	3371	17665		
18:42	20219	3370	21035		
18:52	20203	3367	24402		
19:02	20209	3368	27770		
19:12	20209	3368	31138		
19:22	20168	3361	34500		
19:32	20100	3350	37850		
19:42	20057	3343	41192		
19:52	20030	3338	44531		
20:02	20032	3339	47869		
20:12	19983	3331	51200		
20:22	19982	3330	54530		
20:32	20013	3336	57866		
20:42	19712	3285	61151	***	SET POINT REACHED
20:52	17842	2974	64125		
21:02	15530	2588	66713		
21:12	14714	2452	69165		
21:22	16444	2741	71906		
21:32	12748	2125	74031		
21:42	9832	1639	75669		
21:52	8787	1465	77134		
22:02	12906	2151	79285		
22:12	13780	2297	81582		
22:22	13040	2173	83755		
22:32	12875	2146	85901		
22:42	12113	2019	87920		
22:52	11445	1908	89827		
23:02	10134	1689	91516		
23:12	8891	1482	92998		
23:22	8114	1352	94350		
23:32	9123	1521	95871		
23:42	7138	1190	97060		
23:52	7137	1190	98250		
00:02	6609	1102	99351		
00:12	7359	1227	100578		
00:22	6797	1133	101711		
00:32	6666	1111	102822		
00:42	6723	1121	103942		
00:52	6713	1119	105061		
01:02	6695	1116	106177		
01:12	6613	1102	107279		
01:22	6765	1128	108407		
01:32	6827	1138	109544		
01:42	6392	1065	110610		
01:52	6333	1056	111665		
02:02	6231	1039	112704		
02:12	6431	1072	113776		
02:22	8981	1497	115272		
02:32	6251	1042	116314		
02:42	6330	1055	117369		
02:52	6330	1055	118424		
03:02	2506	418	118842		
03:12	19856	3309	122151		
03:22	19941	3324	125475		
03:32	13148	2191	127666		
03:42	8905	1484	129150		
03:52	8500	1417	130567		
04:02	7686	1281	131848		
04:12	7466	1244	133092		
04:22	7047	1175	134267		
04:32	7046	1174	135441		
04:42	6384	1064	136505		
04:52	2333	389	136894		
05:02	2312	385	137279		
05:12	2313	386	137665		
05:22	2308	385	138049		
05:32	2304	384	138433		
05:42	2314	386	138819		
05:52	2311	385	139204		
06:02	2314	386	139590		
06:12	2312	385	139975		
06:22	2314	386	140361		
06:32	2308	385	140746		
06:42	2314	386	141131	79980	SINCE SET POINT

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TABLE 8

TEST #1 - PIT #11 FUEL CONSUMPTION

FUEL111 J86

TEST #1 : PIT #11 : 13 MARCH 1985 PIT FUEL CONSUMPTION

TIME	BURNER GAS CONSUMPTION RECORDED (SCFH)	IN 10min (SCF)	ACCUMULATED (SCF)	
16:12	3658	610	610	
16:22	3650	608	1218	
16:32	28178	4696	5914	
16:42	28554	4759	10673	
16:52	28647	4775	15448	
17:02	28664	4777	20225	
17:12	28669	4778	25003	
17:22	28685	4781	29784	
17:32	28469	4745	34529	
17:42	28524	4754	39283	
17:52	28333	4722	44005	
18:02	28543	4757	48762	
18:12	28337	4723	53485	
18:22	28309	4718	58203	
18:32	24997	4166	62369	*** SET POINT REACHED
18:42	22597	3766	66136	
18:52	20939	3490	69625	
19:02	19624	3271	72896	
19:12	18496	3083	75979	
19:22	18506	3084	79063	
19:32	17309	2885	81948	
19:42	16188	2698	84646	
19:52	15717	2620	87265	
20:02	15151	2525	89791	
20:12	14375	2396	92186	
20:22	13912	2319	94505	
20:32	13524	2254	96759	
20:42	13009	2168	98927	
20:52	12426	2071	100998	
21:02	11936	1989	102988	
21:12	11330	1888	104876	
21:22	11269	1878	106754	
21:32	10526	1754	108508	
21:42	10346	1724	110233	
21:52	10006	1668	111900	
22:02	9742	1624	113524	
22:12	9417	1570	115094	
22:22	9067	1511	116605	
22:32	8808	1468	118073	
22:42	8566	1428	119500	
22:52	8499	1417	120917	
23:02	8265	1378	122294	
23:12	8140	1357	123651	
23:22	9730	1622	125273	
23:32	7368	1228	126501	
23:42	7385	1231	127732	
23:52	7102	1184	128915	
00:02	6916	1153	130068	
00:12	6755	1126	131194	
00:22	6438	1073	132267	
00:32	6307	1051	133318	
00:42	6188	1031	134349	
00:52	6179	1030	135379	
01:02	5959	993	136372	
01:12	5943	991	137363	
01:22	5822	970	138333	
01:32	5770	962	139295	
01:42	5647	941	140236	
01:52	5600	933	141169	
02:02	5512	919	142088	
02:12	5477	913	143001	
02:22	5440	907	143907	
02:32	5637	940	144847	
02:42	5357	893	145740	
02:52	5374	896	146635	
03:02	5313	886	147521	
03:12	5260	877	148398	
03:22	5191	865	149263	
03:32	5212	869	150131	
03:42	5207	868	150999	
03:52	5080	847	151846	
04:02	4978	830	152676	
04:12	4943	824	153499	
04:22	4933	822	154322	
04:32	4909	818	155140	92770 SINGE SET POINT

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In this case the comparison between the non-recuperative pit (#6) and the recuperative pit (#11) over the total study period, as can be seen from Tables 9 and 10, indicates a fuel saving of 18% for the recuperative pit. All of the savings, it can be noted, occurred in the period up to set point. The fuel consumption of each pit from set point to the end of the study period are within 1% of each other.

As in test #1 the results of comparing the fuel consumption of recuperative and non-recuperative pits is quite inconclusive. There are simply too many variables outside of the combustion/pit system which significantly influence fuel consumption. Among those factors are:

- track time from teeming to soaking pit and hence ingot temperature;
- temperature of pit on placement of ingots;
- variations in combustion efficiencies from pit to pit.

As we were unable to record or account for the above variables it was decided that the energy recovered by preheating the incoming combustion air was the most "controlled" and hence reliable indication of fuel savings. It is assumed that if the energy recovered was not provided by the recuperator an equivalent fuel input would result.

Table 11 shows the results of this computation for test #2. As can be seen the total fuel

TABLE 9

TEST #2 - PIT #6 FUEL CONSUMPTION

FUEL62 J80

TEST #2 : PIT #6 : 27 MARCH 1985 PIT FUEL CONSUMPTION

TIME	BURNER GAS CONSUMPTION RECORDED (SCFH)	IN 10min (SCF)	ACCUMULATED (SCF)	
08:48	3305	551	551	
08:58	3327	555	1105	
09:08	26662	4444	5549	
09:18	26739	4457	10005	
09:28	26743	4457	14463	
09:38	26750	4458	18921	
09:48	26767	4461	23382	
09:58	26746	4458	27840	
10:08	26715	4453	32292	
10:18	26738	4456	36749	
10:28	26693	4449	41197	
10:38	26657	4443	45640	
10:48	26664	4444	50084	
10:58	26494	4416	54500	
11:08	26677	4446	58946	
11:18	26626	4438	63384	
11:28	26638	4440	67823	
11:38	26341	4390	72214	
11:48	25440	4240	76454	*** SET POINT REACHED
11:58	22659	3777	80230	
12:08	20660	3443	83673	
12:18	19756	3293	86966	
12:28	18691	3115	90081	
12:38	17607	2935	93016	
12:48	16389	2732	95747	
12:58	15248	2541	98289	
13:08	14510	2418	100707	
13:18	14040	2340	103047	
13:28	14851	2475	105522	
13:38	12700	2117	107639	
13:48	12054	2009	109648	
13:58	11443	1907	111555	
14:08	10956	1826	113381	
14:18	10524	1754	115135	
14:28	10443	1741	116875	
14:38	9865	1644	118520	
14:48	9698	1616	120136	
14:58	10192	1699	121835	
15:08	8931	1489	123323	
15:18	8835	1473	124796	
15:28	7883	1314	126109	
15:38	7958	1326	127436	
15:48	7799	1300	128736	
15:58	7781	1297	130032	
16:08	7625	1271	131303	
16:18	7465	1244	132547	
16:28	7444	1241	133788	
16:38	7385	1231	135019	
16:48	7507	1251	136270	
16:58	7104	1184	137454	
17:08	6474	1079	138533	
17:18	6502	1084	139617	
17:28	6432	1072	140689	
17:38	6549	1092	141780	
17:48	6429	1072	142852	
17:58	6241	1040	143892	
18:08	6146	1024	144916	
18:18	6097	1016	145932	
18:28	6211	1035	146968	
18:38	6183	1031	147998	
18:48	6124	1021	149019	
18:58	6110	1018	150037	
19:08	6074	1012	151049	
19:18	5969	995	152044	
19:28	5046	841	152885	
19:38	5905	984	153869	
19:48	5849	975	154844	
19:58	5997	1000	155844	
20:08	6026	1004	156848	80394 SINCE SET POINT

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TABLE 10

TEST #2 - PIT #11 FUEL CONSUMPTION

FUEL112 J74

TEST #2 | PIT #11 | 27 MARCH 1985 | PIT FUEL CONSUMPTION

TIME	BURNER GAS CONSUMPTION RECORDED (SCFH)	IN 10 min (SCF)	ACCUMULATED (SCF)		
05:10	3832	639	639		
05:20	3783	631	1269		
05:30	28302	4717	5986		
05:40	28687	4781	10767		
05:50	28612	4769	15536		
06:00	28769	4795	20331		
06:10	28227	4705	25035		
06:20	28566	4761	29796		
06:30	28682	4780	34577		
06:40	28832	4805	39382		
06:50	28614	4769	44151		
07:00	25733	4289	48440	***	SET POINT REACHED
07:10	23863	3977	52417		
07:20	22054	3676	56093		
07:30	20291	3382	59474		
07:40	18991	3165	62640		
07:50	17312	2885	65525		
08:00	15980	2663	68188		
08:10	15462	2577	70765		
08:20	14826	2471	73236		
08:30	14045	2341	75577		
08:40	13361	2227	77804		
08:50	12859	2143	79947		
09:00	12463	2077	82024		
09:10	12606	2101	84125		
09:20	11362	1894	86019		
09:30	10847	1808	87827		
09:40	10728	1788	89615		
09:50	10367	1728	91343		
10:00	10045	1674	93017		
10:10	9740	1623	94640		
10:20	9499	1583	96223		
10:30	9126	1521	97744		
10:40	8793	1466	99210		
10:50	8686	1448	100657		
11:00	8289	1382	102039		
11:10	8103	1351	103389		
11:20	7761	1294	104683		
11:30	7809	1302	105984		
11:40	7600	1267	107251		
11:50	7184	1197	108448		
12:00	6754	1126	109574		
12:10	6479	1080	110654		
12:20	6300	1050	111704		
12:30	6043	1007	112711		
12:40	5987	998	113709		
12:50	5915	986	114695		
13:00	5839	973	115668		
13:10	5699	950	116618		
13:20	6525	1088	117705		
13:30	5392	899	118604		
13:40	5491	915	119519		
13:50	5342	890	120409		
14:00	5374	896	121305		
14:10	5165	861	122166		
14:20	5138	856	123022		
14:30	4009	668	123690		
14:40	7312	1219	124909		
14:50	5460	910	125819		
15:00	4823	804	126623		
15:10	4982	830	127453		
15:20	4883	814	128267	79827	SINCE SET POINT

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TABLE 11

TEST #2 - PIT #11 AIR PREHEAT ENERGY RECOVERED

COMBAIR2 K73

TEST #2 : PIT #11 : 27 MARCH 1985

AIR PRE-HEAT ENERGY RECOVERED

TIME	COMB. AIR FLOW (SCFH)	FLOW IN 10min. (SCF)	PRE-HEAT TEMP. (deg. C)	TEMP. RISE (deg. F)	ENERGY RECOVERED (SCF) 10min	TOTAL
05:10	85606	14268	397	679	174	174
05:20	83002	13834	377	643	160	334
05:30	314183	52364	317	535	504	838
05:40	315295	52549	333	563	533	1371
05:50	314326	52388	348	590	557	1928
06:00	315650	52608	360	612	580	2507
06:10	311605	51934	366	623	582	3090
06:20	314807	52468	369	628	593	3683
06:30	313321	52220	373	635	597	4280
06:40	313387	52231	362	616	579	4859
06:50	313816	52303	355	603	568	5427
07:00	282264	47044	355	603	511	5937
07:10	263688	43948	376	641	507	6444
07:20	242666	40444	386	659	480	6924
07:30	224853	37476	391	668	450	7374
07:40	209403	34901	395	675	424	7798
07:50	187595	31266	398	680	383	8181
08:00	175968	29328	397	679	358	8539
08:10	169089	28182	388	662	336	8875
08:20	164297	27383	390	666	328	9204
08:30	154982	25830	397	679	316	9519
08:40	149430	24905	402	688	308	9827
08:50	142189	23698	403	689	294	10121
09:00	139649	23275	405	693	290	10412
09:10	140021	23337	402	688	289	10701
09:20	125900	20983	400	684	258	10959
09:30	119760	19960	401	686	246	11205
09:40	119546	19924	402	688	247	11452
09:50	114187	19031	402	688	236	11688
10:00	110209	18368	404	691	229	11916
10:10	108939	18157	405	693	226	12143
10:20	105201	17534	407	697	220	12362
10:30	99788	16631	409	700	210	12572
10:40	97261	16210	411	704	205	12777
10:50	94722	15787	413	707	201	12978
11:00	91723	15287	414	709	195	13174
11:10	88087	14681	415	711	188	13361
11:20	85747	14291	416	713	183	13545
11:30	86857	14476	417	715	186	13731
11:40	81946	13658	417	715	176	13907
11:50	79612	13269	417	715	171	14077
12:00	73354	12226	417	715	157	14235
12:10	71502	11917	418	716	154	14388
12:20	70018	11670	419	718	151	14539
12:30	67246	11208	419	718	145	14684
12:40	66421	11070	420	720	143	14827
12:50	64838	10806	421	722	140	14968
13:00	65438	10906	422	724	142	15110
13:10	63101	10517	423	725	137	15247
13:20	75387	12565	425	729	165	15412
13:30	63141	10524	427	733	139	15551
13:40	63595	10599	430	738	141	15692
13:50	63007	10501	433	743	141	15832
14:00	63184	10531	436	749	142	15974
14:10	63217	10536	438	752	143	16117
14:20	62729	10455	440	756	142	16259
14:30	76784	12797	435	747	172	16431
14:40	79338	13223	447	769	183	16614
14:50	64056	10676	442	760	146	16760
15:00	63989	10665	444	763	147	16907
15:10	64250	10708	444	763	147	17054
15:20	63440	10573	446	767	146	17200

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saved over the entire study period is 17,200 SCF. It is interesting to note that although the ten minute period savings are higher in the period up to reaching set point, much of the total savings are accumulated over the longer soaking period.

Table 12 is a comparison of the air preheat energy recovery and the fuel consumed. Percentage savings were computed as discussed in Section 9.1. The comparison indicates a percentage fuel saving of 12% for the entire study period. The saving rarely varies from this average figure over a wide range of fuel inputs.

This estimated saving of 12% compares favorably with other data. The generic energy balance presented in Section 4.0 indicates a saving of 12%. The discussion on recuperators presented in Appendix C estimates the loss in potential savings due to a damaged recuperator at between 10% and 15%. The manufacturer's fuel savings estimation graph, Graph 6, indicates savings of the order of 15 to 17% at the temperature levels recorded.

(iii) Test #3

Test #3 was an attempt to verify the results of test #2 with respect to overall fuel savings. As can be seen from Tables 13 to 15 the percentage saving over the entire study period is again 12%.

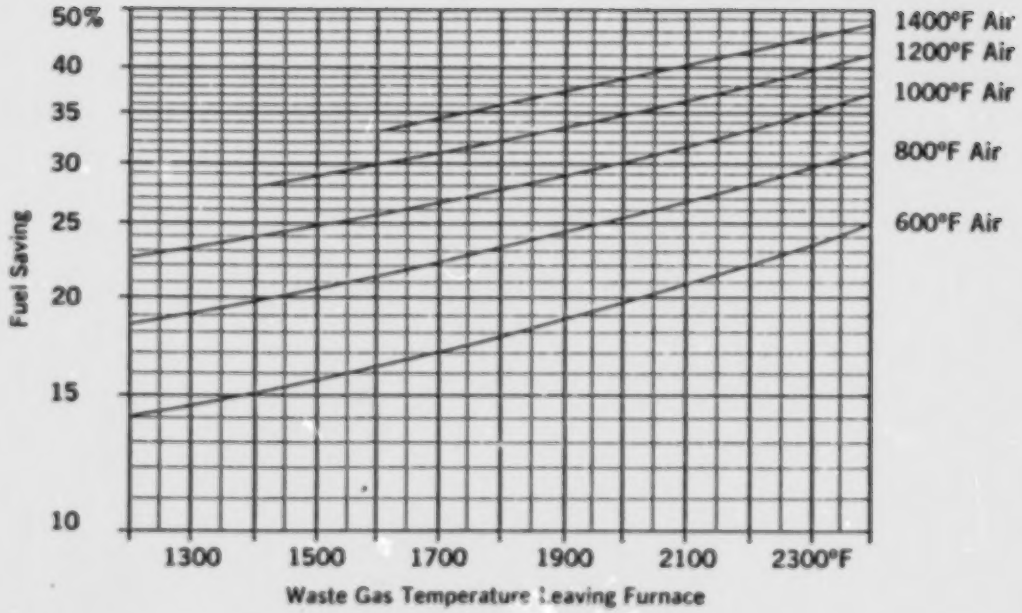
TABLE 12

TEST #2 - PIT #11 AIR PREHEAT FUEL SAVINGS

SAVINGS2 I74

TEST #2 : PIT #11 : 27 MARCH 1985 AIR PRE-HEAT FUEL SAVINGS

TIME	AIR PRE-HEATING ENERGY RECOVERED (SCF) 10min	TOTAL	GAS CONSUMP. (SCFH)	FUEL CONSUMPTION (SCF) 10min	TOTAL	SAVINGS (%) 10min	TOTAL
05:10	174	174	3832	639	639	21	21
05:20	160	334	3783	631	1269	20	21
05:30	504	838	28302	4717	5986	10	12
05:40	333	1171	28687	4781	10767	10	11
05:50	557	1928	28612	4769	15536	10	11
06:00	580	2508	28769	4795	20331	11	11
06:10	582	3090	28227	4705	25035	11	11
06:20	593	3683	28566	4761	29796	11	11
06:30	597	4280	28682	4780	34577	11	11
06:40	579	4859	28832	4805	39382	11	11
06:50	568	5427	28614	4769	44151	11	11
07:00	511	5938	25733	4289	48440	11	11
07:10	507	6445	23863	3977	52417	11	11
07:20	480	6925	22054	3676	56093	12	11
07:30	450	7375	20291	3382	59474	12	11
07:40	424	7799	18991	3165	62640	12	11
07:50	383	8182	17312	2885	65525	12	11
08:00	358	8540	15980	2663	68188	12	11
08:10	336	8876	15462	2577	70765	12	11
08:20	328	9204	14826	2471	73236	12	11
08:30	316	9520	14045	2341	75577	12	11
08:40	308	9828	13361	2227	77804	12	11
08:50	294	10122	12859	2143	79947	12	11
09:00	290	10412	12461	2077	82024	12	11
09:10	289	10701	12606	2101	84125	12	11
09:20	258	10959	11362	1894	86019	12	11
09:30	246	11205	10847	1808	87827	12	11
09:40	247	11452	10728	1788	89615	12	11
09:50	236	11688	10367	1728	91343	12	11
10:00	229	11917	10045	1674	93017	12	11
10:10	226	12143	9740	1623	94640	12	11
10:20	220	12363	9499	1583	96223	12	11
10:30	210	12573	9126	1521	97744	12	11
10:40	205	12778	8793	1466	99210	12	11
10:50	201	12979	8686	1448	100657	12	11
11:00	195	13174	8289	1382	102039	12	11
11:10	188	13362	8103	1351	103389	12	11
11:20	183	13545	7761	1294	104683	12	11
11:30	186	13731	7809	1302	105984	13	11
11:40	176	13907	7600	1267	107251	12	11
11:50	171	14078	7184	1197	108448	12	11
12:00	157	14235	6754	1126	109574	12	11
12:10	154	14389	6479	1080	110654	12	12
12:20	151	14540	6300	1050	111704	13	12
12:30	145	14685	6043	1007	112711	13	12
12:40	143	14828	5987	998	113709	13	12
12:50	140	14968	5915	986	114695	12	12
13:00	142	15110	5839	973	115668	13	12
13:10	137	15247	5699	950	116618	13	12
13:20	165	15412	6525	1088	117705	13	12
13:30	139	15551	5392	899	118604	13	12
13:40	141	15692	5491	915	119519	13	12
13:50	141	15833	5342	890	120409	14	12
14:00	142	15975	5374	896	121305	14	12
14:10	143	16118	5165	861	122166	14	12
14:20	142	16260	5138	856	123022	14	12
14:30	172	16432	4009	668	123690	20	12
14:40	183	16615	7312	1219	124909	13	12
14:50	146	16761	5460	910	125819	14	12
15:00	147	16908	4823	804	126623	15	12
15:10	147	17055	4982	830	127453	15	12
15:20	146	17201	4883	814	128267	15	12



GRAPH 6

MANUFACTURER'S ESTIMATED FUEL SAVINGS

TABLE 13

TEST #3 - PIT #11 FUEL CONSUMPTION

FUEL113 K52

TEST #3 : PIT #11 : 12-APRIL-1985 PIT FUEL CONSUMPTION

TIME	BURNER GAS CONSUMPTION RECORDED (SCFH)	IN 10min (SCF)	ACCUMULATED (SCF)	
02:52	2657	443	443	
03:02	2686	448	890	
03:12	28085	4681	5571	
03:22	28482	4747	10318	
03:32	28514	4752	15071	
03:42	28628	4771	19842	
03:52	28526	4754	24596	
04:02	27541	4590	29186	*** SET POINT REACHED
04:12	23847	3975	33161	
04:22	21059	3510	36671	
04:32	18731	3122	39793	
04:42	17157	2860	42652	
04:52	15977	2663	45315	
05:02	14977	2496	47811	
05:12	14150	2358	50169	
05:22	13617	2270	52439	
05:32	13174	2196	54635	
05:42	12546	2091	56726	
05:52	12047	2008	58733	
06:02	11544	1924	60657	
06:12	11019	1837	62494	
06:22	10208	1701	64195	
06:32	9930	1655	65850	
06:42	9493	1582	67432	
06:52	9351	1559	68992	
07:02	8491	1415	70407	
07:12	8443	1407	71814	
07:22	8156	1359	73173	
07:32	8059	1343	74516	
07:42	7806	1301	75817	
07:52	7656	1276	77093	
08:02	7324	1221	78314	
08:12	7138	1190	79504	
08:22	7068	1178	80682	
08:32	6850	1142	81823	
08:42	6561	1094	82917	
08:52	6622	1104	84021	
09:02	6068	1011	85032	
09:12	10725	1788	86819	
09:22	2748	457	87276	
09:32	2813	469	87745	58558 SINCE SET POINT

KEEN***KEEN*****KEEN*****KEEN*****KEEN*****KEEN*****KEEN*****KEEN*****KEEN*****KEEN***

TABLE 14

TEST #3 - PIT #11 AIR PREHEAT ENERGY RECOVERED

COMBAIR3 K52

TEST #3 : PIT #11 : 12 APRIL 1985

TIME	COMB. AIR FLOW (SCFH)	FLOW IN 10min. (SCF)	PRE-HEAT TEMP. (deg. C)	AIR PRE-HEAT ENERGY RECOVERED TEMP. RISE (deg. F)	ENERGY RECOVERED (SCF) 10min	TOTAL
02:52	112819	18803	367	625	211	211
03:02	114081	19014	339	574	197	408
03:12	308935	51489	313	527	489	897
03:22	310350	51725	335	567	528	1425
03:32	309834	51639	353	599	557	1982
03:42	309642	51607	361	614	570	2552
03:52	309842	51640	363	617	574	3126
04:02	303259	50543	361	614	558	3684
04:12	261617	43603	357	607	476	4160
04:22	233011	38835	367	625	437	4597
04:32	206736	34456	376	641	397	4994
04:42	189529	31588	385	657	374	5368
04:52	174018	29003	394	673	351	5719
05:02	166050	27675	401	686	342	6061
05:12	156582	26097	403	689	324	6385
05:22	151554	25259	405	693	315	6700
05:32	145836	24306	406	695	304	7004
05:42	139018	23170	409	700	292	7296
05:52	131498	21916	410	702	277	7573
06:02	126965	21161	412	706	269	7842
06:12	121473	20246	414	709	258	8100
06:22	111410	18568	417	715	239	8339
06:32	106392	17732	418	716	229	8568
06:42	102707	17118	419	718	221	8789
06:52	101052	16842	420	720	218	9007
07:02	92768	15461	415	711	198	9205
07:12	92708	15451	421	722	201	9406
07:22	90926	15154	421	722	197	9603
07:32	90186	15031	422	724	196	9798
07:42	84998	14166	422	724	185	9983
07:52	85750	14292	423	725	187	10170
08:02	79286	13214	424	727	173	10343
08:12	78341	13057	425	729	171	10514
08:22	78409	13068	426	731	172	10686
08:32	75793	12632	429	736	167	10853
08:42	73155	12193	430	738	162	11015
08:52	72327	12055	430	738	160	11175
09:02	65209	10868	425	729	143	11318
09:12	118826	19804	413	707	252	11570
09:22	116267	19378	403	689	240	11811
09:32	118256	19709	403	689	245	12055

KEEN***KEEN*****KEEN*****KEEN*****KEEN*****KEEN*****KEEN*****KEEN*****KEEN*****KEEN***

TABLE 15

TEST #3 - PIT #11 AIR PREHEAT FUEL SAVINGS

SAVINGS3 I53

TEST #2 : PIT #11 : 27 MARCH 1985 AIR PRE-HEAT FUEL SAVINGS

TIME	AIR PRE-HEATING ENERGY RECOVERED (SCF)		GAS CONSUMP. (SCFH)	FUEL CONSUMPTION (SCF)		SAVINGS (%)	
	10min	TOTAL		10min	TOTAL	10min	TOTAL
02:52	211	211	2657	443	443	32	32
03:02	197	408	2686	448	890	31	31
03:12	489	897	28085	4681	5571	9	14
03:22	528	1425	28482	4747	10318	10	12
03:32	557	1982	28514	4752	15071	10	12
03:42	570	2552	28628	4771	19842	11	11
03:52	574	3126	28526	4754	24596	11	11
04:02	558	3684	27541	4590	29186	11	11
04:12	476	4160	23847	3975	33161	11	11
04:22	437	4597	21059	3510	36671	11	11
04:32	397	4994	18731	3122	39793	11	11
04:42	374	5368	17157	2860	42652	12	11
04:52	351	5719	15977	2663	45315	12	11
05:02	342	6061	14977	2496	47811	12	11
05:12	324	6385	14150	2358	50169	12	11
05:22	315	6700	13617	2270	52439	12	11
05:32	304	7004	13174	2196	54635	12	11
05:42	292	7296	12546	2091	56726	12	11
05:52	277	7573	12047	2008	58733	12	11
06:02	269	7842	11544	1924	60657	12	11
06:12	258	8100	11019	1837	62494	12	11
06:22	239	8339	10208	1701	64195	12	11
06:32	229	8568	9930	1655	65850	12	12
06:42	221	8789	9493	1582	67432	12	12
06:52	218	9007	9355	1559	68992	12	12
07:02	198	9205	8491	1415	70407	12	12
07:12	201	9406	8443	1407	71814	12	12
07:22	197	9603	8156	1359	73173	13	12
07:32	196	9799	8059	1343	74516	13	12
07:42	185	9984	7806	1301	75817	12	12
07:52	187	10171	7656	1276	77093	13	12
08:02	173	10344	7324	1221	78314	12	12
08:12	171	10515	7138	1190	79504	13	12
08:22	172	10687	7068	1178	80682	13	12
08:32	167	10854	6850	1142	81823	13	12
08:42	162	11016	6561	1094	82917	13	12
08:52	160	11176	6622	1104	84021	13	12
09:02	143	11319	6068	1011	85032	12	12
09:12	252	11571	10725	1788	86819	12	12
09:22	240	11811	2740	457	87276	34	12
09:32	245	12056	2813	469	87745	34	12
KEEN***	KEEN*****	KEEN*****	KEEN*****	KEEN*****	KEEN*****	KEEN*****	KEEN*****

9.4 Combustion Analysis

The flue gas temperatures before and after the recuperator presented in Table 6 agree with those obtained from the computerized control and monitoring system.

Readings were taken at maximum, medium and low fire points in the cycle.

For the recuperator pit the O_2 readings varied from 2½ to 4½% indicating excess air percentages of 12 to 21%, respectively. In view of the above variance in % excess air it is estimated that a fuel saving of the order of 2% is possible by the addition of oxygen trim to control and monitor the combustion process.

For the non-recuperative pit the O_2 readings varied from 4 to 7.5% indicating excess air quantities of 19 to 36%, respectively. In view of this variance in % excess air it is estimated that a fuel saving of the order of 7½% is possible by the addition of oxygen trim.

10.0 Related Discussion

10.1 General

In the course of our work it quickly became obvious both from our on-site observations, discussions and literature search that the soaking pit process has significant potential for fuel savings beyond recuperation and combustion improvements. In view of the non-intrusive nature of our study these points can only be discussed in general terms. These external factors are discussed below.

10.2 Operating Practice

The soaking pit is an example of a furnace where the fuel consumption of the heating equipment is significantly controlled by operating factors totally outside the equipment itself.

It is reported[2] that there exists the potential of saving 20% to 25% on most soaking pit facilities in the area of operating practice - not related to the soaking pit.

The largest potential area of savings is in the area between the pouring station and the pit itself. The temperature of the ingots when charged in the pit is, of course, controlled by the time between finish pour and finish charge - referred to as track time. The ideal situation is to strip the ingot molds and get the ingots into the pits in the shortest possible time - this being somewhat controlled by solidification times for the various size ingots, as well as other factors. The point is that most mills set up a so-called target track time which is the ideal track time from the standpoint of being minimum. Equally, track times are often far in excess of the target track time which means that excessive heat in

the ingots is lost to atmosphere between the pouring station and the pit. Actual track times may run five hours where the target track time is three and a half hours, and this has a tremendous effect on energy consumption resulting, it is reported,[2] in roughly 40% more pit time. Therefore, a detailed study is required in a given mill to determine what the target track time should be, what actual track times are, the resultant effect on energy consumption, and most importantly, why the actuals substantially exceed the targets.

10.3 Ingot Placement

Another area of potential savings relates to the charging practice in the pit itself. If we place two 38" x 62" ingots tightly together in a pit, they are most difficult to heat, as compared to being spaced apart. The entire charge must be held in the pit substantially longer, energy is needlessly used in order to heat the pit for the longer period of time and in general, the ingots are not properly heated which can mean downgrading due to quality problems. There is a crane operator involved whose job it is to space the ingots uniformly in the pit. This is not always possible. The pit bottom must be in a reasonable shape to allow him to set the ingots where he wants. Equally, the ingot mold sets on a stool, which may be in bad condition and we end up with ingots which have rounded butts. It is virtually impossible to stand these ingots up in a pit so they are generally either leaned against the wall or leaned against other ingots which again leads to poor charging practice. Thus, the procedure should be to determine whether the pit loading is good or bad. If bad, why? This, then, will isolate the areas needing attention such as stool condition, pit bottom condition, or crane operator performance.

Industry standards for ingot placement are often expressed as percentage hearth coverages. Figure 5 illustrates another method of determining satisfactory ingot placement.

10.4 Pit Cover

Another energy saving concerns the heat losses from soaking pits as well as from the ingots when they are removed from the soaking pits; the last ingot removed being relatively cold on most occasions. By dividing the soaking pit covers into two parts, only that part of the soaking pit is opened where the current ingot is located. This design, it is reported, can save 50% of the radiation losses during discharge and, in addition, is beneficial to rolling time.

Application of a two-piece soaking pit cover is illustrated in Figure 6.

10.5 Wall Insulation

To minimize the loss of heat from pit walls it is essential to reconsider the material and thickness of the wall. A heat insulation recently employed is veneering.

In batch type furnaces, such as soaking pits, the heat lost when the pit cover is opened is large. Therefore, a veneering insulation which reduces radiation losses makes a significant contribution. A comparison of the effect of a conventional and ceramic fibre veneer wall is shown in Figure 7.[4]

It is reported,[4] however, that there are problems with veneer insulation: the joining method and the short service life due to vibrations of the pit and contact with ingots.

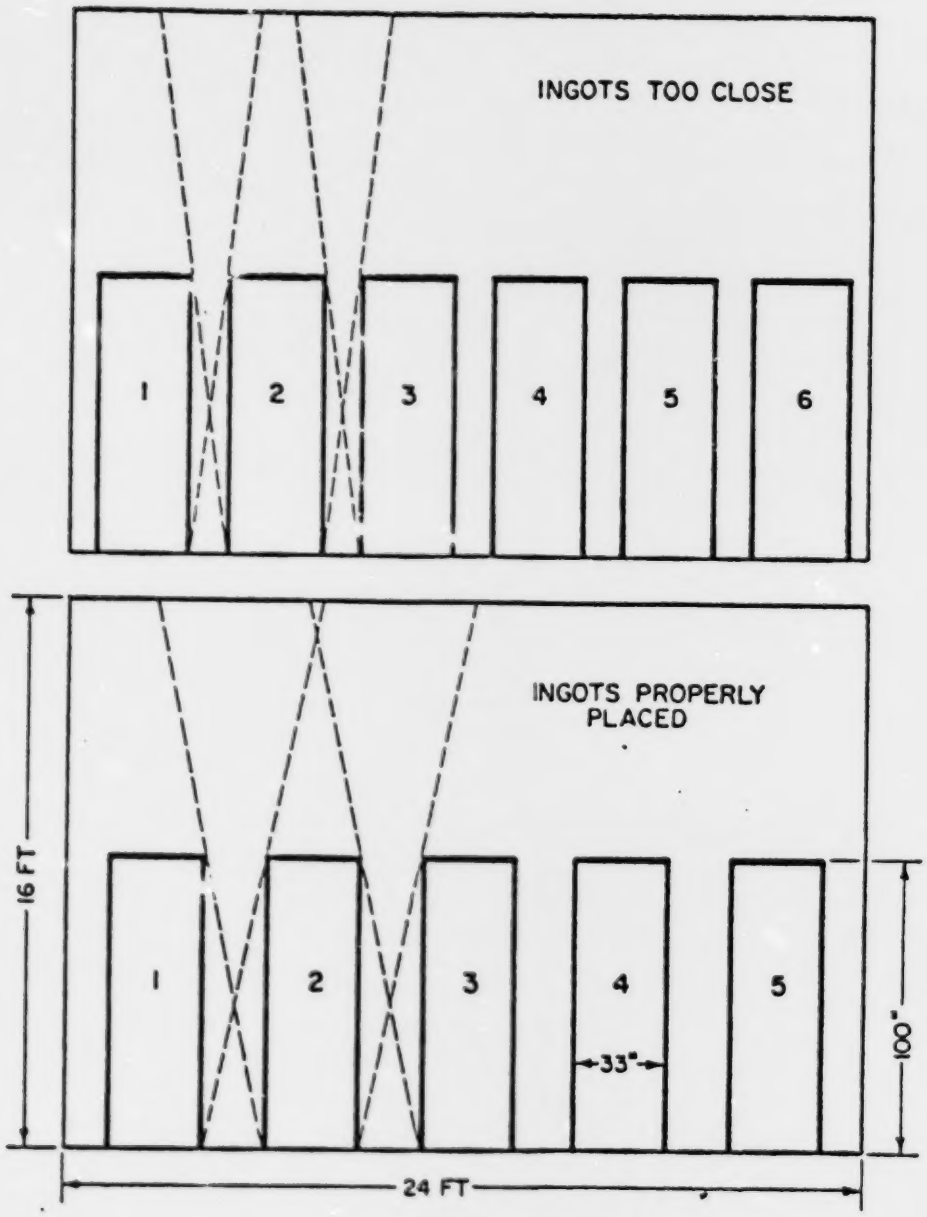


FIGURE 5 - INGOT PLACEMENT

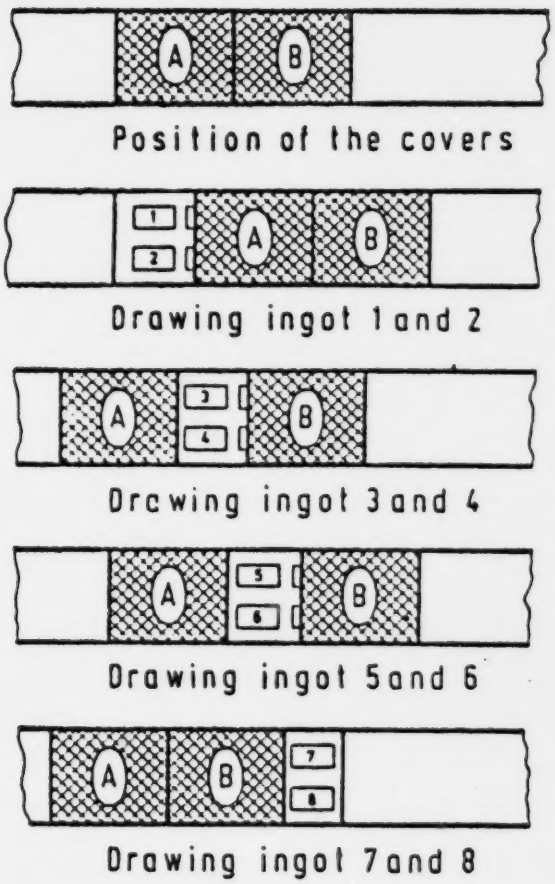
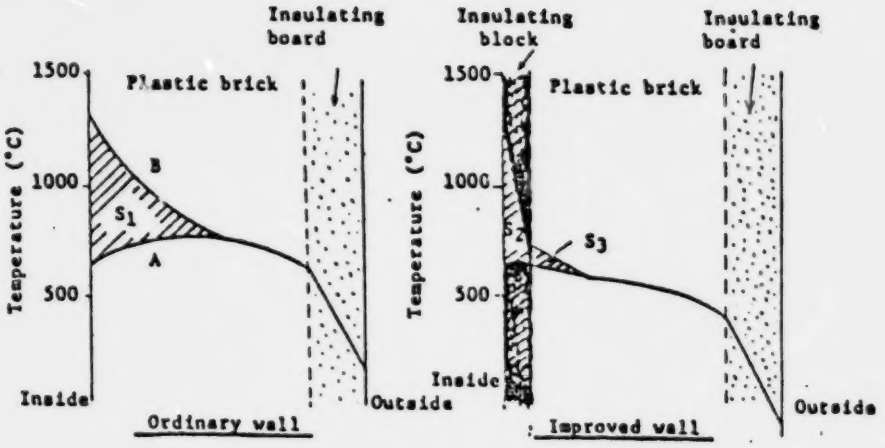


FIGURE 6 - TWO-PIECE SOAKING PIT COVER



$S_1 > S_2 + S_3$

FIGURE 7 - PIT WALL TEMPERATURE DISTRIBUTION

11.0 Conceptual Design

11.1 Recuperation

The design of a recuperator retrofit for the nine pits currently without heat recovery is guided by virtue of the fact that four recuperative systems exist side by side.

Figure 8 indicates the major equipment of a recuperative pit in schematic form. Appendix D contains equipment specifications for the major combustion components of a recuperative pit. The major components of any retrofit to a non-recuperative pit would thus be:

- installation of recuperator including re-routing of flue gases and combustion air;
- replacement of combustion and dilution air blowers with units capable of overcoming the higher system static pressures;
- burner replacement;
- revision to control systems.

Based on the above we estimate the cost of a single non-recuperative pit retrofit as follows:

Recuperator, including installation	$100,000.00
Re-routing of flue gases and combustion air	$40,000.00
New fans, including installation	$40,000.00
New burner	$20,000.00
Controls revisions	$10,000.00
TOTAL	$210,000.00

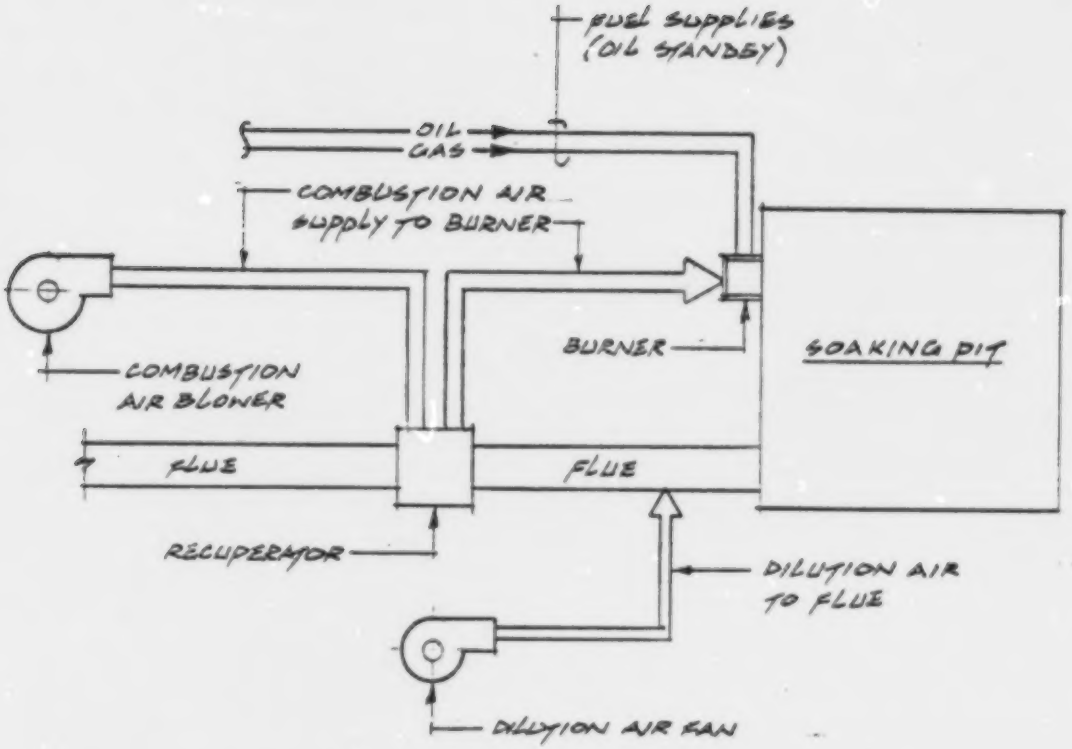


FIGURE 8 - RECUPERATIVE PIT SCHEMATIC

The above equipment figures were obtained from the respective equipment manufacturers.

11.2 Combustion Control

Western Combustion Services Ltd. estimate that the cost of providing O_2 trim to provide better combustion control is of the order of $25,000.00 per pit.

12.0 Economic Analysis

12.1 Recuperation

In Section 9, Data Analysis, it was established that recuperation can provide fuel savings of 12%.

In the calendar year 1983, the thirteen soaking pits at the IPSCO INC. Regina plant consumed a total of 33×10^6 cubic meters of natural gas. We are informed that no preference is given to the recuperator pits and thus it is reasonable to assume that on average each pit handles a similar load. Thus, allowing for the 12% saving of the four recuperator pits, the consumption per pit is $(33 \times 10^6)/[(9 \times 1) + (4 \times 0.88)]$ or 2.64×10^6 cubic meters. Current Saskatchewan Power Corporation charges of 12.4 cents/cubic meter result in a fuel cost of $327,360.00 per pit per year. Thus the potential savings per pit are 12% of the above figures, or 316,800 cubic meters of gas at a cost of $39,283.00, say. $40,000.00 per pit per year.

From Section 11, Conceptual Design, it was estimated that the cost of the retrofit per pit was approximately $210,000.00. Thus the retrofit project simple payback is 210,000/40,000 or 5.25 years.

Over the nine non-recuperative pits the total potential annual saving is 2.85×10^6 cubic meters at a current cost of $353,550.00.

12.2 Combustion Control

In Section 9, Data Analysis, it was established that for the two pits sampled the potential fuel savings were 2% and 7½%. It is worth noting that the newer recuperative pit, of which

there are four, was the more efficient of the two. The nine remaining pits are of a vintage similar to the non-recuperative pit tested and found to have potential combustion improvement savings of the order of 7½%.

Thus a simple numerical average, i.e., (7 x 7.5) + (4 x 2.0)/13, gives an approximation of 4.65 or, say, 4% overall possible saving.

Applied to the annual consumption quoted above, a 4% saving represents 1.32×10^6 cubic meters of natural gas at a cost of $163,680.00.

At a capital cost of $25,000.00 per pit for the required O_2 trim, the simple payback period is therefore (13 x 25,000)/163,680 or 1.99, say, 2 years.

Thus, for the IPSCO INC. Regina plant a complete retrofit project of installing nine recuperators plus accessories and thirteen combustion control systems would save approximately $517,230.00 per year. The retrofit cost would be of the order of $2,215,000.00 resulting in a net project simple payback of 4.28 years.

13.0 Other Potential Applications

13.1 General

Within the steelmaking industry the use of recuperators and improvements in combustion controls is directly applicable to both soaking pits and reheat furnaces. The nature and use of each type of furnace was discussed in an earlier section.

The above energy saving techniques are also widely applicable in any large fuel fired boilers or process heaters.

In an effort to determine more specific information on further applications within the steel industry a telephone survey of Canadian steel manufacturers was performed. Companies contacted were those listed in the 1984 Directory of Iron and Steel Plants published by the Association of Iron and Steel Engineers of Pittsburgh, Pa. The results of the survey were far from satisfactory. Many of the companies contacted regarded the information we requested to be of a proprietary nature. What information we did obtain is presented in Table 16.

13.2 Recuperation

On the basis of the data presented in Table 16 it seems reasonable to assume that there are a minimum of 31 soaking pits/reheat furnaces of approximately 1250 x 10^6 BTU/H input capacity currently operating without recuperation. Assuming production schedules similar to IPSCO INC.'s one can extrapolate from the savings presented in Section 9.

TABLE 16

CANADIAN STEEL INDUSTRY SURVEY

Company	Plant	Soaking Pits			Reheat Furnaces		
		No.	Total Input x 10^6 BTU/H	Recu-perators	No.	Total Input x 10^6 BTU/H	Recu-perators
Atlas Steel	Welland, Ontario	12	9.5	No	2	N/A	No
		5	12.5	No			
Dofasco Inc.	Hamilton, Ontario	50 - 60	20 - 50	Yes	None	-	-
Western Canada Steel Ltd.	Vancouver, B.C.	None	-	-	1	0.15	No
	Calgary, Alberta	None	-	-	1	0.12	No
Ivaco Inc.	L'Orignal, Ontario	None	-	-	1	100	Yes
Lake Ontario Steel	Whitby, Ontario	None	-	-	1	210	Yes
					1	155	No
Stelco Inc.	Hamilton, Ontario	36	24.0	Yes	7	180	Yes
		18	20.0	No	3	180	No

Other steel producers contacted who would not provide the required information include Burlington Steel, Union Drawn Co. Ltd., Courtice Steel Ltd. and Stanley Precision Ltd.

IPSCO INC. installed input capacity = 340×10^6 BTU/H

IPSCO INC. annual fuel consumption = 33×10^6 cubic meters

By proportion approximate consumption at surveyed plants is:

$$\frac{1250}{340} \times 33 \times 10^6 \doteq 120 \times 10^6 \text{ cubic meters}$$

$$12\% \text{ saving} = 120 \times 0.12 \times 10^6$$

$$= 14.4 \times 10^6 \text{ cubic meters}$$

Thus the 31 soaking pits/reheat furnaces noted above could have the potential, through retrofit, of reducing their energy consumption by 14.4×10^6 cubic metres of natural gas. At the fuel costs quoted for IPSCO INC. this is equivalent to a saving of approximately $1.8 million per year.

13.3 Combustion Control

Table 16 indicates that there are soaking pits/reheat furnaces having a minimum total input capacity of the order of 5.6×10^9 BTU/H in Canada. In view of the incomplete nature of the response to our survey this is likely a conservative estimate.

If even a 2% decrease in fuel consumption were possible, as above the fuel savings would be:

$$\frac{5600}{340} \times 33 \times 10^6 \times 0.02 = 10.9 \times 10^6 \text{ cubic meters}$$

or $1.3 million per year at the fuel costs quoted for IPSCO INC.

14.0 Conclusions and Recommendations

By virtue of the steel making process the energy consumed by soaking pits in reheating ingots prior to hot rolling into slabs or coiled sheets is significantly influenced by both pit design and external factors.

Important external factors which influence pit energy consumption are:

- the track time, or time from teeming (pouring) the ingot to delivery to the soaking pit significantly influences the temperature of the ingot and hence the energy required to reheat it;
- ingot placement or spacing within the pit influences rate and uniformity of heating and thus time in the pit and fuel consumed.

Pit design features of necessity influence fuel consumption. Some of the major influences are:

- lack of recuperation, i.e., recovery of heat from flue gases to incoming combustion air;
- poor combustion control;
- pit cover design and use with respect to placing and removal of ingots; pit temperature is significantly affected by removal of the cover;
- insulation system, as in any fuel consuming device, is critical.

The test data obtained indicates that the use of recuperators to preheat combustion air in soaking pits has the potential to save 12% of the energy used in the process. The fuel savings and necessary capital costs of the required retrofit indicate a simple payback period of 5.25 years.

Flue gas analysis of a sample number of pits indicates that the soaking pits at IPSCO INC.'s Regina plant have the potential to save 4% by providing better control of combustion. The estimated savings and required capital costs result in a simple payback period of two years for the combustion control improvements.

It is our recommendation with respect to the IPSCO INC. Regina steelworks soaking pits that:

(i) recuperators be installed on the existing nine presently non-recuperative pits;

(ii) combustion control trim be installed on all soaking pits;

(iii) an in-depth study of plant operation be undertaken in an effort to minimize the effect external factors have on pit fuel consumption;

(iv) a formal scheduled maintenance program be implemented to maintain the combustion equipment and associated controls.

With respect to application of the energy conserving measures discussed above to other plants and industries it can be said that:

(i) although recuperators are commonly installed on soaking pits (and reheat furnaces) there are a significant number of installations operating without recuperation. A brief survey of the Canadian steel industry indicates minimum savings from recuperation of the order of $2 million per year.

(ii) combustion control improvements through O_2 monitoring and burner control offer the potential of saving in excess of $1 million per year in the Canadian steel industry.

(iii) other fuel saving techniques discussed in general terms offer potential for at least a 10% saving in soaking pit/reheat furnace operations. This is a saving of approximately $7 million per year.

(iv) the potential for application of the energy saving techniques discussed in this report to other industries and processes is unlimited.

We strongly recommend that the process being continued by the current Enersolve projects be continued in an effort to identify and educate concerned parties as to the vast potential for energy savings in our industrial processes.

15.0 Further Project Costs

The estimated project costs of implementing modifications and monitoring performance are presented below.

Phase I:

Present pre-engineering assessment

Fixed fee contract $15,200.00

Phase II:

Detailed engineering plan for modifications and costs for Phases III and IV

Engineering fee @ 10% of cost of work

Estimated cost of retrofit from Section 11 is $2,215,000.00

Hence 10% x $2,215,000 . . . . . $221,500.00

Phase III:

Retrofit of equipment, commissioning and acceptance by the owner of upgraded systems

Estimated cost of retrofit from Section 11 . . . . . $2,215,000.00

Phase IV:

Nine month monitoring and maintenance of upgraded facility

Monitoring at 20 h/month @ $50/h for 9 months	$9,000.00
Report re monitoring services	$5,000.00
Maintenance by manufacturer and IPSCO INC. personnel	no cost

Phase IV costs $14,000.00

APPENDIX A

Keen Engineering Co. Ltd.'s Response to RFP

10th January 1985

The Secretary
Supply Administration
Supply & Services Canada
Room 1 - 335
Place du Portage, Phase III
11 Laurier Street
HULL, Quebec
K1A 0S5

Dear Sir,

Re: DSS File Number 02SQ.23440-4-9283
Pre-Engineering Assessment of Enersolve
Demonstration Project

1. Proposal Submission

Keen Engineering Co. Ltd., Regina, Saskatchewan, submits the following for approval and acceptance.

2. Technical Proposal

2.1 Specific Site Identification

Ipsco Inc.
Armour Road
Regina, Saskatchewan

Manager of Engineering: Mr. D. Willoughby

2.2 Description of Plant

Ipsco Inc. is a major Western Canadian steel manufacturer, producing approximately 1 million tons per year.

Ingots, as opposed to billets, are reheated in gas fired 'soaking pits' prior to being hot rolled into coiled sheet steel. Ingots are similar to, but larger than, billets, weighing approximately 15 tons each. The term 'soaking pit' is derived from the fact that the ingot is soaked in hot air.

The Ipsco Inc. plant has thirteen separate soaking pits with a combined maximum gas input of 100 MW (340 million BTU/h).

. 2

Four of the thirteen pits are provided with flue gas/combustion air economisers which recover heat from the flue gases and use it to preheat incoming combustion air.

All thirteen soaking pits are provided with extensive computerized monitoring equipment. The conditions in any one pit can be monitored from the pit control room.

Deterioration of combustion control equipment and related maintenance is also thought to offer significant potential for efficiency improvements.

2.3 Proposed Work

Our proposed scope of work has seven main elements.

(i) Through extensive on-site investigation and testing establish data base including fuel use, equipment and combustion efficiencies and load characteristics;

(ii) Through above field work assess effectiveness of existing equipment;

(iii) Assess potential for:

(a) heat recovery on nine soaking pits currently without economisers;

(b) combustion control improvements;

(iv) Perform conceptual design work based on results of elements (i) to (iii), inclusive;

(v) Estimate the economic benefit of the proposed upgrading, including capital and maintenance costs;

(vi) Briefly extrapolate results and estimate potential for application to other similar facilities;

(vii) Estimate project costs for remaining three phases.

2.4 Preliminary Economic Analysis

During an inspection of the facility, pits 10 - 13, those having economisers, were monitored. It was noted that the incoming combustion air was being heated from -10°C to 265°C. The air flow was 27,132 scmh (292,060 scfh) per pit. This free preheating of the combustion air would otherwise consume the equivalent of 400 CMH of natural gas.

. 3

Based on the installed burner capacity of 100 MW and the annual natural gas consumption of 40 million cubic meters the estimated equivalent full load run time is 3,150 hours.

Hence the economiser saving of 400 CMH over 3,150 hours is equivalent to 1.26 million cubic meters per year.

At the present rate of 11.3 cents per cubic meter this represents an annual saving of $142,380.00.

Applied to the other nine soaking pits, and simply extrapolating from the above figures, the potential annual savings which might be provided by installing economisers is of the order of $300,000.00.

Operating personnel also indicate that combustion efficiency is not as high as it could be. Even a 2% increase in combustion efficiency would correspond to an annual saving of 40×10^6 CM $\times$ .02 = 0.8×10^6 CM or $90,000.00.

The estimated capital cost of each economiser is $150,000.00 installed. The simple payback is therefore $\frac{9 \times 150,000}{300,000} = 4.5$ years.

The combined effect of combustion improvements and consideration of true paybacks will result in a net payback of less than four years.

2.5 Presentation

The presentation will be in report form with the following main sections:

Executive Summary
Report Summary
Problem Definition
Methodology
Data
Existing Equipment Effectiveness
Potential Savings
Conceptual Design
Economic Considerations
Extrapolation Potential
Cost Estimates

The report will be prepared by Mr. Tanner and Mr. Sawers.

. 4

2.6 Project Estimates

Phase I:	Present pre-engineering survey	$15,200.00
Phase II:	Detailed engineering design for modifications and costs for Phases III and IV	$100,000.00
Phase III:	Retrofit of equipment, commisioning and acceptance by the owner of up-graded systems	$1,350,000.00
Phase IV:	Nine month monitoring and maintenance of up-graded facility	$20,000.00

2.7 Personnel

G.H. Tanner, P.Eng. . . . . Senior Technical Investigator
J.G. Grant, P.Eng. . . . . Process and Combustion Control Specialist
J.B. Sawers, P.Eng. . . . . Technical Investigator and Coordinator

Resumes of the above individuals are attached.

2.8 Organization and Experience

Please refer to attached brochure.

3. Price Proposal

3.1 Labour	Hours	Rate	Total
G.H. Tanner	80	60	4,800
J.G. Grant	60	55	3,300
J.B. Sawers	80	50	4,000
Word Process	60	30	1,800
			13,900

3.2 Sub-Consultants

Electrical: Alfa Engineering Ltd.
2909 Saskatchewan Drive
Regina, Saskatchewan

Mr. R. Mah, P.Eng.

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3.3 Travel and Living

Local, no charge.

3.4 Fee

Fee $15,200.00

Based on estimated required hours and subconsultant's fee.

The price quoted is based on costs computed in accordance with the schedule of recommended fees to prime consultants for the Association of Professional Engineers of Saskatchewan.

4. Management Proposal

4.1 Contract Plan and Report Form

Attached.

4.2 Project Manager

G.H. Tanner, Vice-President

5. Method of Payment

Preferably monthly progress payments once study is underway.

We trust the above is sufficient information for your present purposes. Please do not hesitate to contact the writer should you require clarification or further details. We look forward to hearing from you regarding our proposal.

Yours truly,
KEEN ENGINEERING CO. LTD.

James B. Sawers, P.Eng.
Principal

xc: Ipsco Inc., Mr. D. Willoughby

APPENDIX B

IPSCO INC. Profile

IPSCO INC. Profile

IPSCO INC. is the fifth largest steel producing company in Canada, primarily marketing in Western North America with a heavy emphasis on pipe and tubular products for the energy sector. The company was founded in 1956 and its shares are publicly traced on the Toronto and Alberta stock exchanges.

Since incorporation in Regina, Saskatchewan, IPSCO INC. has expanded to include pipe operations in Calgary, Edmonton, and Red Deer, Alberta, and Port Moody, British Columbia. Sales offices are located across Canada in Vancouver, Calgary, Edmonton, Regina, Winnipeg, Toronto, and Montreal. The principal office of IPSCO STEEL INC., a wholly-owned subsidiary, is Houston, Texas, with sales offices in Minneapolis, Minnesota, Denver, Colorado and Billings, Montana. The total number of employees, including production and engineering staff, is approximately 1,700.

In addition to the head office, IPSCO Regina houses the steelworks and pipeworks on 185 acres. Two hundred and forty-two people are employed in the Regina office, 597 in the steelworks and 208 in the pipeworks.

The Regina steelworks consists of an electric arc furnace melt shop, a rolling mill, and a finishing mill, which produce steel skelp and hot rolled sheet and plate. The finishing facility is currently being modernized to include a cut-to-length line, a high speed slitter and a coil build-up line. The modernization will be complete early in 1985.

IPSCO INC. electric arc furnace melting in conjunction with ladle metallurgy, including TN Desulphurization, produces steels of superior microcleanliness, which are enhanced by bottom pouring and ladle stream shrouding. This has led to the development of

IPSCO FINE GRAIN steel and a line of special products - IPSCO ARCTIC GRADE steel and high frequency welded line pipe for sour gas applications.

The Regina Pipeworks include two ERW (Electric Resistance Weld) pipe mills and two spiral weld pipe mills, producing welded steel line pipe, hollow structural sections, and other welded steel pipe.

The INSCO INC. Research and Development Centre, opened in Regina in 1981, reaffirms the company's commitment to leadership in the manufacture of high strength steels for specific or difficult applications, and high grade steel pipe produced to tolerances far more stringent than those specified by the American Petroleum Institute.

APPENDIX C

Recuperator Basics

Recuperator Basics

The various names or designations applied to heat exchangers are partly an attempt to describe their function and partly the result of tradition within certain industries. For example, a recuperator is a heat exchanger which recovers waste heat from the exhaust gases of a furnace to heat the incoming air for combustion. This is the name used in both the steel and the glass making industries. The heat exchanger performing the same function in the steam generator of an electric power plant is termed an air preheater, and in the case of a gas turbine plant, a regenerator.

However, in the glass and steel industries, the word generator refers to two chambers of brick checkerwork which alternately absorb heat from the exhaust gases and then give up part of that heat to the incoming air. The flows of flue gas and of air are periodically reversed by valves so that one chamber of the regenerator is being heated by the products of combustion while the other is being cooled by the incoming air. Regenerators are often more expensive to buy and maintain than recuperators, and their application is primarily in glass melt tanks and in open hearth steel furnaces.

It must be pointed out, however, that although their functions are similar, the three heat exchangers mentioned may be structurally quite different as well as different in their principal modes of heat transfer.

The simplest configuration for a heat exchanger is the metallic radiation recuperator which consists of two concentric lengths of metal tubing. The inner tube carries the hot exhaust gases while the external annulus carries the combustion air from the atmosphere to the air inlets of the furnace burners. The hot gases are cooled by the incoming combustion air which now carries additional energy

into the combustion chamber. This is energy which does not have to be supplied by the fuel; consequently, less fuel is burned for a given furnace loading.

The saving in fuel also means a decrease in combustion air and therefore, stack losses are decreased not only by lowering the stack gas temperatures, but also by discharging smaller quantities of exhaust gas. This particular recuperator gets its name from the fact that a substantial portion of the heat transfer from the hot gases to the surface of the inner tube take place by radiative heat transfer. The cold air in the annulus, however, is not affected by infrared radiation so that only convection heat transfer takes place to the incoming air.

The two gas flows are usually parallel, although the configuration would be simpler and heat transfer more efficient if the flows were opposed in direction (or counterflow). The reason for the use of parallel flow is that recuperators frequently serve the additional function of cooling the duct carrying away the exhaust gases, and consequently extending its service life.

The inner tube is often fabricated from high temperature materials such as stainless steels of high nickel content. This gives a large temperature differential expansion, since the outer shell is usually of a different and less expensive material. And the mechanical design must take this effect into account. More elaborate designs of radiation recuperators incorporate two sections: the bottom operating in parallel flow and the upper section using the more efficient counterflow arrangement. Because of the large axial expansions experienced and the stress conditions at the bottom of the recuperator, the unit is often supported at the top by a free standing support frame with an expansion joint between the furnace and recuperator.

A second common configuration for recuperators is the tube type or convective recuperator. The hot gases are carried through a number of parallel small diameter tubes, while the incoming air to be heated enters a shell surrounding the tubes and passes over the hot tubes one or more times in a direction normal to their axes.

If the tubes are baffled to allow the gas to pass over them twice, the heat exchanger is termed a two-pass recuperator; if two baffles are used, a three-pass recuperator, etc. Although baffling increases both the cost of the exchanger and the pressure drop in the combustion air path, it increases the effectiveness of heat exchange. Shell- and tube-type recuperators are generally more compact and have a higher effectiveness than radiation recuperators, because of the larger heat transfer area made possible through the use of multiple tubes and multiple passes of the gases.

The principal limitation on the heat recovery of metal recuperators is the reduced life of the liner at inlet temperatures exceeding 2000^{o}F. At this temperature, it is necessary to use the less efficient arrangement of parallel flows of exhaust gas and coolant in order to maintain sufficient cooling of the inner shell. In addition, when furnace combustion air flow is dropped back because of reduced load, the heat transfer rate from hot waste gases to preheat combustion air becomes excessive, causing rapid surface deterioration. Then, it is usually necessary to provide an ambient air by-pass to cool the exhaust gases.

In order to overcome the temperature limitations of metal recuperators, ceramic tube recuperators have been developed, whose materials allow operation on the gas side to 2800^{o}F and on the preheated air side to 2200^{o}F on an experimental basis, and to 1500^{o}F on a more or less practical basis. Early ceramic recuperators were built of tile and joined with furnace cement, and thermal cycling caused

cracking of joints and rapid deterioration of the tubes. Later developments introduced various kinds of short silicon carbide tubes which can be joined by flexible seals located in the air headers. This kind of patented design maintains the seals at comparatively low temperatures and has reduced the seal leakage rates to a few percent.

Earlier designs had experienced leakage rates from 8 to 60 percent. The new designs are reported to last two years with air preheat temperatures as high as 1300°F, and much lower leakage rates.

An alternative arrangement for the convective type recuperator, is where the cold combustion air is heated in a bank of parallel vertical tubes which extend into the flue gas stream. The advantage claimed for this arrangement is the ease of replacing individual tubes, which can be done during full capacity furnace operation. This minimizes the cost, the inconvenience, and possible furnace damage due to a shutdown forced by recuperator failure.

For maximum effectiveness of heat transfer, combinations of radiation type and convective type recuperators are used, with the convective type always following the high temperature radiation recuperator.

Although the use of recuperators conserves fuel in industrial furnaces, and although their original cost is relatively modest, the purchase of the unit is often just the beginning of a somewhat more extensive capital improvement program. The use of a recuperator, which raises the temperature of the incoming combustion air, may require purchase of high temperature burners, larger diameter air lines with flexible fittings to allow for expansion, cold air lines for cooling the burners, modified combustion controls to maintain the required air/fuel ratio despite variable recuperator heating, stack dampers, cold air bleeds, controls to protect the

recuperator during blower failure or power failures, and larger fans to overcome the additional pressure drop in the recuperator. It is vitally important to protect the recuperator against damage due to excessive temperatures, since the cost of rebuilding a damaged recuperator may be as high as 90 percent of the initial cost of manufacture and the drop in efficiency of a damaged recuperator may easily increase the fuel costs by 10 to 15 percent.

Recuperators are used for recovering heat from exhaust gases to heat other gases in the medium to high temperature range. Some typical applications are in soaking pits, annealing ovens, melting furnaces, afterburners and gas incinerators, radiant-tube burners, reheat furnaces, and other gas to gas waste heat recovery applications in the medium to high temperature range.

APPENDIX D

Recuperative Pit Major Equipment List

Recuperative Pit Major Equipment List

The major equipment installed on the existing recuperative pits, as taken from the materials list, is detailed below.

Recuperator: "Thermal Transfer" flue type recuperator arrangement 9 (7 + 7) 3¼ inch diameter tubes as per Thermal Transfer Corporation drawing EF2214 Rev..'C' c/w 63 x 3¼ inch O.D. x 5/16 inch wall x 6 foot 4 inch effective length grade HE centrifugally cast tubes and necessary tube inserts, 63 x 3¼ inch O.D. x 5/16 inch wall x 6 foot 4 inch effective length grade HD centrifugally cast tubes and necessary tube insert, 1 expansion joint for hot bank, flanged inlet and outlet, 1 air return bend, 1 steel support frame and required castable refractory and fibre packing. Design data - fuel, natural gas @ 1000 BTU/ft^3, standby No. 2 fuel oil. Fuel input - 30 M^2BTU/hr, waste gas flow (no dilution) 5,780 SCFM, - with dilution 6,700 SCFM, waste gas temperature (no dilution) 2200^oF, - entering recuperator 1950^oF, exiting recuperator 1310^oF, pressure drop 0.45 inch W.C., combustion air flow - 5,270 SCFM, entering recuperator 70^oF and exiting @ 1000^oF, pressure drop 6.50 inches W.C., heat exchange rate 5.593 M^2BTU/hr.

Burner: "North American" #6818-54-26 VHP Burner rated capacity 30 M^2BTU/HR using 1000^oF preheated combustion air @ rate of 33,000 SCFH at 10 inches W.C. pressure and 1000 BTU/FT^3 natural gas or standby #2 fuel oil and atomizing air @ rate of 27,200 SCFH @ 14 O.S.I. cold - as per 'North American' Drawing #C7-1909 Revision 2.

Combustion Air Blower:	"Chicago Blower" - combustion air fan, size 2400, type PA, design 2300A, arrangement 8, clockwise rotation, vertical upblast discharge c/w flanged inlet and outlet connections, "Falk" Steel-Flex coupling and inlet silencer to reduce sound level to -85dBA @ 3 feet from fan rated at 6200 CFM and 36 inches SP @ 70°F and 3500 RPM using 54.9 BHP as per "C.B." drawing D23-0-177CN.
Dilution Air Blower:	"Chicago Blower" dilution air fan, size 15 type SQAD, arrangement 4, clockwise rotation, vertical upblast discharge c/w flanged inlet and outlet connections and inlet screen, rated at 4118 CFM and 10 inches W.C. SP @ 70°F and 3500 RPM using 8.4 BHP as per "C.B." drawing #CU-28187.

APPENDIX E

Western Combustion Services Ltd. Report

Western Combustion Service Ltd.
SPECIALIZING IN BOILER & BURNER REPAIRS
CONTROLS & COMBUSTION ANALYSIS
550 · 10th AVENUE · REGINA, SASK. S4N 5P2 · PHONE 522-8494

April 19, 1985

Keen Engineering Ltd.
2060 Broad Street
Regina, Saskatchewan
S4P 1Y3

ATTENTION: Jim Sawyers

Dear Sir:

We are submitting the following combustion readings from the soaking pits at Ipsco. Readings were taken on #8 pit (no recuperator) and #12 pit (with recuperator). Please refer to tables below.

Pit #12 (Recuperator)

Readings	%O_2	°C Flue Gas After Recup	°C Flue Gas Before Recup	ft^3/hr Gas Flow	Pre-Heat Combustion Air
1	2½	577°C	858°C	29,700	382°C
2	2½	584	866	29,900	381°C
3	3 3/4	520	750	14,340	407
4	4	519	757	13,340	417
5	4¼	515	750	11,760	420
6	4½	493	747	4,568	417
7	4½	473	749	7,399	430

As indicated in above chart, flue gas exit temp varies from 584°C to 473°C (1050°F to 880°F) down quite substantially from inlet temp of 866°C to 747°C (1600°F to 1400°F) and with preheated air at 430°C to 381°C (800°F to 725°F) as indicated in fuel savings chart. This relates to an approximate fuel saving of 20-25%. Note: This system was designed for approximately 800°F combustion air.

On the oxygen readings we vary from 2½ to 4½% O_2. 2% O_2 would be an ideal situation if it could be maintained. If flue gas temperature after recuperator is maintained at approximately 1000°F, then above readings could be improved by use of a continuous oxygen trim system and if maintained at 2% O_2 throughout range without combustibles would result in a savings of approximately 2%. I'm sure that even this small percentage of savings would be quite substantial when related to total fuel cost over a one year period for this pit. I will also mention that out of the 13 pits this is the unit which runs with the best results.

Approximate cost of 0_2 equipment required to tie into existing control system to enable the use of 0_2 trim would be approximately $25,000. These figures can be used when calculating payback.

Pit #8 (no recuperator)

Reading

	0_2	°C Flue Gas Temp	Gas ft^3.hr Flow
Hi	4%	975°C	25,000
Mid	6.5%	963°C	15,000
Lo	7.5%	947°C	5,000

Note: Above 0_2 readings are fairly close to being accurate but flue temps are slightly low due to continuous water spray which cools the flue.

If we relate back to fuel savings chart and assume 800°F combustion air temps we would then realize an approximately 25% savings over present. This would require installing special burners and controls which could handle these temperatures as well as the installation of recuperators. Capital cost of such equipment would be approximately $150,000 to $200,000 per pit plus installation.

On the other hand, oxygen trim equipment would cost approximately $25,000 and if we relate to the chart on energy conservation page we find that if we controlled 0_2 content at 2% even at 1800°F flue gas, savings would be in the 5-10% range. Probably a much better payback would result with 0_2 for only a fraction of initial capital cost.

In closing, I would like to make the following comments on our findings in this system and they are virtually true in all combustion systems.

1. Flue gas discharge temp in excess of 800°F is worthwhile recapturing in some form of useable energy. When temperatures exceed 1200°F the most practical method with the greatest payback is to preheat the combustion air.

2. Oxygen trim or at least continuous indication with manual trim should be incorporated in all systems over 20,000,000 BTU/hr.

3. The next most important feature is maintaining a positive pressure if possible in combustion zone. This in most cases is the least expensive of the three upgrading systems and can have some of the greatest effect on fuel consumption.

4. Finally, in my opinion, the most important factor over all the above is maintenance, for without proper maintenance of the burners, controls, air handling equipment or recuperators the capital outlay for such equipment can never prove itself, repayed in the manner that well maintained equipment, especially of this size will over a short period of time.

Hoping this meets with your requirements. Please contact me if we can be of additional service to you.

Yours truly,

Dale Paschinski

BIBLIOGRAPHY

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3 Iron & Steel Engineer Magazine, April 1974. "Soaking pit heating rate improvements", RA Shannon

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